DOCUMENT RESUME

ED 047 520 EM 008 748

AUTHOR	Rigney, Joseph W.
TITLE	Implications of Research on Internal Processing Operations in Learning and Memory for Serial Task Training.
INSTITUTION	University of Southern California, Los Angeles. Dept. of Psychology.
SPONS AGENCY	Office of Naval Research, Washington, D.C. Personnel and Training Research Programs Office.
REPORT NO	TR-67
PUB DATE	Jan 71
NOTE	120p.
EDRS PRICE	EDRS Price MF-$0.65 HC-$6.58
DESCRIPTORS	Associative Learning, Attention Control, Computer Assisted Instruction, *Conditioning, *Learning Processes, Learning Theories, *Literature Reviews, *Mediation Theory, Memory, Recall (Psychological), Retention, *Serial Learning, Stimulus Behavior, Training, Transfer of Training, Visualization

ABSTRACT

The literature on learning research pertaining to the internal processing operations of the learner was reviewed. The current thinking of learning theorists regarding the nature and importance of these processes in learning and retention is described, and their significance for instructional technology is examined. Verbalization, imagery, and organization engaged in by the learner during periods of rehearsal and self-initiated recall have been shown by theorists to have surprisingly strong positive effects on learning and retention. These internal processing operations, as well as the habit of selective attention, are worthy of immediate consideration by the instructional technologist. Two courses of action are suggested: programmatic research on these processes in the context of meaningful material, using appropriate "learning induction mechanisms," and reorientation of the goals and methods of instructional technology to give greater emphasis to "learning to learn." (Author/MT)

ERIC

BEHAVIORAL TECHNOLOGY LABORATORIES

ED047526

Technical Report No. 67

IMPLICATIONS OF RESEARCH ON INTERNAL PROCESSING OPERATIONS IN LEARNING AND MEMORY FOR SERIAL TASK TRAINING

January 1971

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY.

DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF SOUTHERN CALIFORNIA

Technical Report No. 67

IMPLICATIONS OF RESEARCH ON INTERNAL PROCESSING OPERATIONS IN LEARNING AND MEMORY FOR SERIAL TASK TRAINING

January 1971

Joseph W. Rigney

<u>Prepared for</u>

Personnel and Training Research Programs
Psychological Sciences Division
Office of Naval Research

Contract N00014-67-A-0269-0012
Contract Authority Identification No. NR 154-295

Reproduction in whole or in part is permitted for any purpose of the United States Government

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Behavioral Technology Laboratories University of Southern California Los Angeles, California 90007	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

IMPLICATIONS OF RESEARCH ON INTERNAL PROCESSING OPERATIONS IN LEARNING AND MEMORY FOR SERIAL TASK TRAINING

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report 67 January 1971

5. AUTHOR(S) (First name, middle initial, last name)

Joseph W. Rigney

6. REPORT DATE January 1971	7a. TOTAL NO. OF PAGES 97	7b. NO. OF REFS 109

8a. CONTRACT OR GRANT NO. N00014-67-A-0269-0012 b. PROJECT NO. NR 154-295 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report 67 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Personnel and Training Research Programs Psychological Sciences Division Office of Naval Research

13. ABSTRACT

The literature of learning research in which the internal processing operations of the learner were studied was reviewed. The current thinking of learning theorists regarding the nature and importance of these processes in learning and retention is described. The significance of this research for instructional technology is examined. It appears that this research marks the beginnings of a science of learning ability which may ultimately result in marked improvements in learning and retention. Verbalization, imagery, and organization engaged in by the learner during periods of rehearsal and self-initiated recall have been shown by theorists to have surprisingly strong positive effects on learning and retention. These internal processing operations, and selective attention, are worthy of immediate consideration by the instructional technologist. Two courses of action are suggested: programmatic research on these processes in the context of meaningful material, using appropriate "learning induction mechanisms", and reorientation of the goals and methods of instructional technology to give greater emphasis to learning to learn. (U)

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

Unclassified
Security Classification

ERIC

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
computer-aided instruction						
training						
learning and memory						
learning to learn						
transfer of training						
serial-task learning						

ERIC Full Text Provided by ERIC

ACKNOWLEDGMENTS

The support of Dr. Victor Fields, Personnel and Training Research Branch, and of Dr. Glenn L. Bryan, Psychological Sciences Division, Office of Naval Research, is gratefully acknowledged.

ABSTRACT

The literature of learning research in which the internal processing operations of the learner were studied was reviewed. The current thinking of learning theorists regarding the nature and importance of these processes in learning and retention is described. The significance of this research for instructional technology is examined. It appears that this research marks the beginnings of a science of learning ability which may ultimately result in marked improvements in learning and retention. Verbalization, imagery, and organization engaged in by the learner during periods of rehearsal and self-initiated recall have been shown by theorists to have surprisingly strong positive effects on learning and retention. These internal processing operations, and selective attention, are worthy of immediate consideration by the instructional technologist. Two courses of action are suggested: programmatic research on these processes in the context of meaningful material, using appropriate "learning induction mechanisms", and reorientation of the goals and methods of instructional technology to give greater emphasis to learning to learn.

ERIC

TABLE OF CONTENTS

ERIC

LIST OF FIGURES

ERIC

IMPLICATIONS OF RESEARCH ON INTERNAL PROCESSING
OPERATIONS IN LEARNING AND MEMORY FOR
SERIAL TASK TRAINING

SECTION I. INTRODUCTION

It is necessary at the outset to say what this report is not going to be. It is not going to be a general review of the literature of learning theory. Well-known, excellent, recent reviews of major aspects of this literature exist in reports and books, e.g., Melton, 1964; Gagne, 1967; Spence and Spence, 1968; Glaser, 1968; 1970; Bower and Spence, 1969; Estes, 1970; Dixon and Horton, 1968; Neimark and Estes, 1967; Hilgard and Bower, 1966; and Tapp, 1969.

The general problems in relating this theory to the requirements of training and education have been pointed out many times, by friendly and by unfriendly critics. There are differences, the effects of which are unknown, between laboratory and classroom; meaningful and nonsense material; isolated items and structured content; short, highly-controlled, repeated trials and loosely controlled exposure to content extending over days, weeks, months and years; experimental learning paradigms and educational and training procedures; and rats, pigeons, or primates, and humans. Yet, the need for theory to guide training and educational practice never has been so apparent as it is now.

This type of literature search needs some boundaries, since at most, only a small fraction of the literature can be examined. A noteworthy trend apparent in the recent literature of learning and memory (e.g., Estes, 1970; Atkinson and Wickens, 1970; Paivio, 1969; Scandura, 1970;

Gagne, 1970; Bower, 1970a, 1970b; Norman, 1968; Mandler, 1968; Neisser, 1967; Pribram, 1969; and Montague and Kiess, 1968) is the interest in the effects of the learner's internal processing operations on learning and memory. These operations are recognized by these theorists as primary considerations for improving learning and retention, and as currently neglected possibilities for teaching students how to learn. Learning to learn, many of these theorists tell us, is at least as important as, and probably more important than learning content.

Internal processing operations which are current topics for research will be reviewed, and the proposition that these and related processes might be brought under control and used to facilitate learning and performance of serial-tasks will be examined.

It is necessary to specify the meaning of some terms that will be used throughout the report, to avoid possible confusion over terminology. The terms "mediating process" and "mediational theory" seem to have been pre-empted by S-R, or behavior, theorists. To them, mediating processes are strings of lower case s's and r's with m subscripts, representing bridges across their no man's land between external stimulus events, signified by capital S, and observable responses, signified by capital R. Since our interests in internal processes are much broader than this conception allows, we will use different terms, which hopefully will be clear to the reader. "Internal processing operations" will denote the set of internal processes which are or could be used by the individual who is learning or performing. We recognize that many of these are still unknown. What goes on at a neurological level during these events is almost a complete mystery. Furthermore, some internal processing operations appear to

be under the voluntary control of the organism while others, possibly the majority, evidently are not. We will define subsets of internal processing operations as follows. "Learning facilitators" will be internal processing operations that in some way improve learning and memory. "Learning inhibitors" will be such operations that impede learning and memory in some way. Correspondingly, "performance facilitators" will denote internal processing operations that assist the performer in performing serial tasks, and "performance inhibitors" will be applied to internal processing operations that in some way decrease the adequacy of performance of these tasks. We will be especially concerned in the following pages with facilitational processes which might be identified and manipulated in learning situations. We share the conviction that better understanding of and control over internal processing operations may lead to order of magnitude improvements in training, education, and performance.

ERIC

SECTION II. CHARACTERISTICS OF SERIAL-TASK PERFORMANCE

Human work is oriented toward attaining goals. It usually is the case that there is some final goal and a number of intermediate, subgoals. Because humans are so constructed that they must perform activities in sequence, work is accomplished by the serial attainment of successive subgoals until the final goal is reached. It also usually is the case that each subgoal can be attained by several or many alternative series of actions. Each action, in turn, has its own small goal. The structure of work is composed of serial-action tasks which can be described in terms of action-goal hierarchies.

Elements of task structures are information-sampling actions, state-changing actions, and goals of actions. Each action has a goal, but some goals can be achieved only by several actions. Since only one or a few actions can be performed at a time, and some goals must be attained before others, elements of task structures are sequentially organized. Information-sampling actions select particular information from the environment. The performer is not a passive receiver. He must be instructed, or he instructs himself, to select certain kinds of information. This may be as simple as the orienting reflex or may involve using special devices to transduce energy for human receptors. State-changing actions do work on objects or symbols to change their relationship with the surrounding context. The actions performed on objects in the environment may require only muscular movements or they may involve tools which are under the control of muscular movements.

A way of describing a task structure which includes all the correct ways to perform the task was reported in earlier work (Rigney and Towne, 1969). In essence, the intermediate goals and the priority-ordering among them; and the actions required to accomplish each goal and the sequence constraints among them, are identified. Subgoals, actions, and the relationships among them then can be represented in various ways. They can be shown in a diagram, or they can be described in English or they can be listed in a format suitable for input to a computer program.

Many varieties of tasks can be described in this way, including those required to troubleshoot devices. In these, the final goal is to determine the cause of a malfunctioning device. To do this, it is necessary to observe the states of functions and elements of the device. This requires performing information-sampling actions, called tests, to obtain information about the state of the device that will allow successive elimination of functions and elements of the device as possible causes.

In the structure of troubleshooting, the results of tests become subgoals. These tests are selected by the performer according to some decision rule or rules (e.g., select tests to reduce the fault area as rapidly as possible) which he expects will lead to the final goal, identification of the faulty element. There may be more than one acceptable next test at each next step; their priority-ordering is not predetermined. But, once a set of legal tests is described, priority-orderings can be generated from decision rules. We see, then, that troubleshooting usually is a mixture of procedural tasks and problem solving tasks.

There is no completely specified task structure until the work situation is analyzed. There will be obvious elements in the situation

ERIC

upon which information-sampling and state-changing actions may be performed. The results of these actions may or may not be apparent in the situation. But, analyzing the work into subgoals, priority-ordering them, and discovering the patterns of actions that will attain each, must be done, either beforehand by an analyst, or during the performance by the performer. As a prescription to be followed, a task description makes at least some assumptions about the performer's capabilities. If it is for someone who has never done such a task before, it must be more detailed and explicit than if it is for someone who has learned the task already. It may be necessary only to tell the latter the name of the task.

One way of teaching the performance of serial-tasks could start with prescriptions detailed enough to allow any student to perform the tasks successfully, even if this required an instruction for performing each simple action. The student would begin as a kind of trusting robot, performing each action as instructed, without necessarily comprehending what he was doing. This fully externally-instructed method will be called the baseline method. Although this method sometimes is used, usually at the very beginning of learning to perform,[1] its value to us is in the concept of a baseline. It provides a reference point for analysis and classification of experimental paradigms and training methods intended to change behavior. It indicates the fundamental role of task description in serial-task training. It reminds us that, even if the learner is forced

[1]Something very close to the baseline method was used on some assembly lines for electronic devices, to facilitate changing over to the assembly of a new device. The workers, usually women, were fully instructed by colored slides and audio tapes, in the step-by-step procedures they were to perform.

ERIC

to play the role of a trusting robot, he brings much more to the learning situation than the baseline method assumes.

SECTION III. WHAT IS LEARNED?

Observations of students learning to perform serial tasks suggest that they gain more internal control over their performance and become less dependent upon external instructions. If they are learning how to operate or troubleshoot a device, they evidently develop internal representations of that device which guide their behavior in relation to it. Some expert technicians can troubleshoot a device from verbal reports of others, without ever going near the device itself. They can describe exactly how to set up test equipment, how to operate the device, and how to perform the other maintenance activities required. Some experienced aviators can describe how to perform the maneuvers required for various missions. They can describe operating procedures they have learned necessary to perform those maneuvers.

It seems evident to us that these experts have developed internal representations of the tasks and devices involved in their performances and are able to use these representations effectively. To be sure, these internal representations may be incomplete -- the aviator may not be able to draw a cockpit with all controls and indicators in their proper locations. The expert maintenance technician may not know some infrequently used preventive maintenance procedure. This simply means that the work they do does not ordinarily involve those controls and indicators or that procedure.

Two fundamental questions here are: "What is learned?", and "How is it learned?" Neither can be answered in terms of processes in the central

nervous system. No one can directly observe internal processing operations there, nor can anyone directly observe neurophysiological changes which presumably are the basis of the changes in performance from which we infer learning. Yet, there seems to be growing recognition in the recent literature on learning and memory of the importance of internal processes. References to rehearsal (Atkinson and Schiffrin, 1968); non-verbal and verbal imagery (Bower, 1970a); organization (Bower and Winzenz, 1969; Bower, 1970b); imagery (Paivio, 1969); internalization (Adams, 1968); natural language mediators (Montague, et al., 1966); scanning mechanisms (Sternberg, 1969); and attributes of memory (Underwood, 1969); attest to this interest.

In this section, we shall examine the literature directed to the question of what is learned. In the following section the question of how it is learned will be similarly approached.

Modern Association Theory

Inferences about internal processing operations drawn from the classical research on learning strike the instructional technologist as extraordinarily limited. Until recently, most of the research that has been done in this area has not been addressed to these operations. However modern association theorists recognize higher levels of organization of internal processes, as the following excerpt from Estes (1970) clearly shows:

> "It should be recognized that the conception of the organism in modern association theory is considerably richer than a bundle of reflexes or stimulus-response bonds. The specific version which, I believe, now marshals broadest support is a stimulus-response formulation at the level of performance, but not at the level of learning, conceived as an inference from performance. In order to be rigorously testable and to be practically useful in the

guidance and management of training and education, learning theory must provide detailed analyses and predictions of the changes in an individual's dispositions to respond to stimuli or classes of stimuli that develop as a function of experience."

"... the associative process is conceived to be, not a matter of switching connections of a response from one stimulus to another, but rather the learning of relations between events. The connection between learning and performance involves feedback relationships in which the process of response selection is continually modified by anticipations of rewarding and punishing consequences."

"... only a drastic misconception of modern association theory could put it in opposition to views which emphasize the importance of structure and organization in behavior as, for example, the 'structure-of-intellect' theory of Guilford (1967). On the contrary, the basic properties of the associative process lead to the formation of progressively higher-order perceptual and motor units. The result of an extended period of learning is not simply a proliferation of associative relations between elementary stimuli and motor reactions, but rather a hierarchical organization of associative relations between stimulus and response patterns of varying levels of complexity." (pp. 7-8)

Furthermore, more research is being directed to internal processing operations in learning and memory. The methodological problems are very great. Internal processing operations must be inferred from experimental observations, and it is difficult to so arrange external conditions that there is an unequivocal interpretation of results.

The emergent characteristics of organismic processes also is a complication. Analyses at different levels of organization of the organism may not be immediately relatable. The psychobiologists (*e.g.*, Groves and Thompson, 1970) seek neural correlates for types of plasticity of the nervous system, *e.g.*, habituation, in simpler parts of the nervous system (spinal cord), or in simpler organisms such as invertebrates or

insects. Others working at the neurological level (e.g., Deutsch, 1966) look to changes in concentrations of chemical transmitters at the synapse for neural correlates of learning, or to some aspect of intraneural protein synthesis for memory coding. The fundamental importance of discoveries at this level is clear. However, we see no way at present to get from this level to an internal processing level, where we might discover operations the human learner uses or could use to learn serial tasks. For example, habituation and the orienting reflex must surely be involved in learning processes at higher levels of organization, but just how still is a matter for speculation (Magoun, 1969; Pribram, 1969).

Osgood (1963) has described a general, three-stage mediation-integration model of decoding, association, and encoding processes, in which the three stages represent successively higher levels of organization. This three-stage mediation-integration model reproduced in Figure 1, illustrates a behavior theorist's approach to answering the question of what is learned.

Osgood's brand of behavior theory, which he calls a three-stage behavior theory, is one of several varieties. He (1968) distinguished among these in his discussion of the psycholinguistic status of contemporary behavior theory in the following general terms:

> "In the first and simplest case, there is single-stage S-R theory; it has two versions, (Pavlovian) conditioning and (Skinnerian) operant learning. Second, there is the type of nonrepresentational mediation theory, represented by Bousfield, Jenkins, and others, and somewhat more complexly by Braine. Third, there are several varieties of representational mediation theory, represented by Mowrer and myself among many others. Finally, there is a three-stage behavior theory, utilizing S and R constructs but including S-S and R-R association as well as S-R association (both single and two-staged), which -- as far as I know -- is uniquely my own. These varieties have been described in the literature in considerable detail." (p. 496)

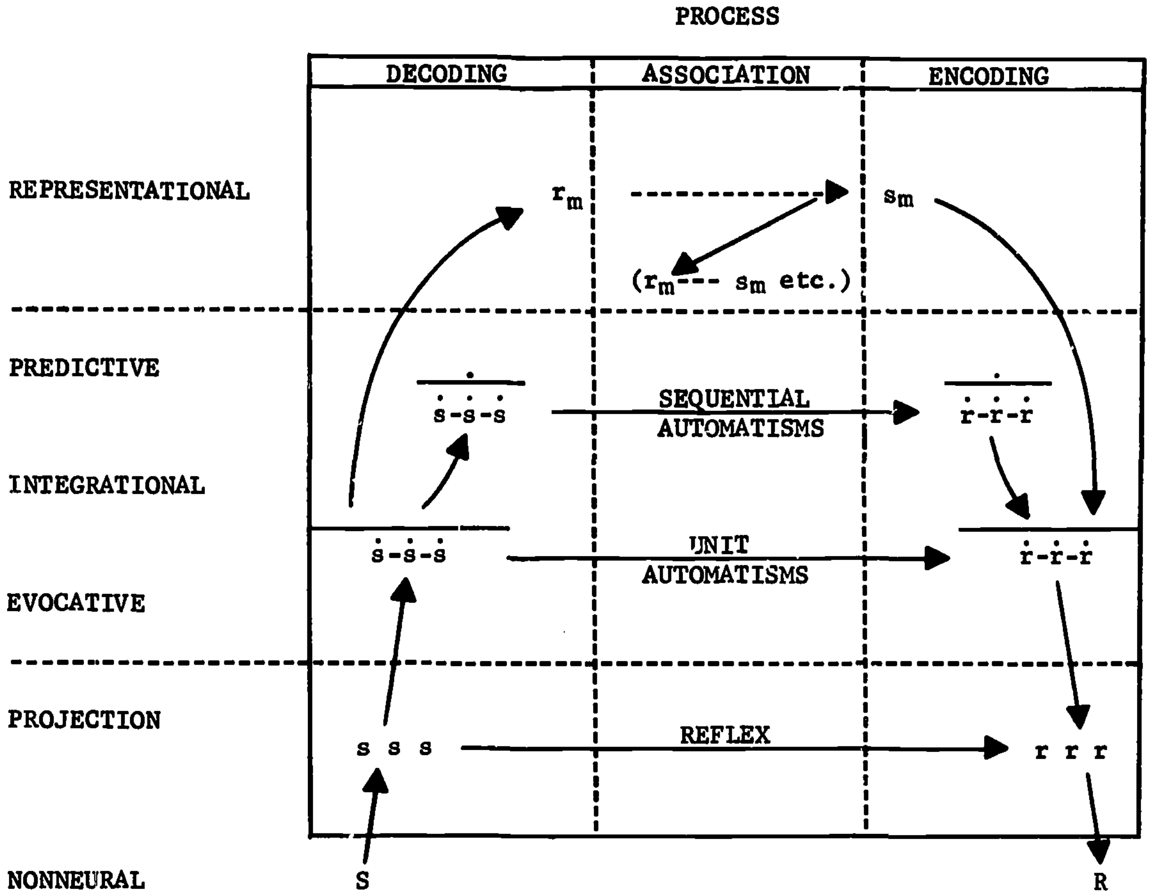


Fig. 1. Three-stage mediation-integration model. (Osgood, 1963, p. 740)

(In behavior theorist's analyses, decoding generally refers to abstracting elements from stimulus events, while encoding generally refers to assembling or organizing appropriate response patterns. Others, e.g., Pribram (1969) use these two terms in exactly the opposite way.)

Osgood (1968) elaborated on the distinctions among these types of behavior theory at greater length and in more detail than can be reviewed here. He maintained that his variety is not, strictly speaking, an S-R theory, since he found it necessary to add an integration level or stage to both decoding and encoding processes in order to incorporate the

essential characteristics of Gestalt theories of perceptual organization and the essential characteristics of motor skill, as these relate to linguistic perceptual and response units. He described this integration level as follows:

> "The underlying principle is this: the greater the frequency (redundancy and contiguity) with which sensory signals at the termini of sensory projection systems, or motor signals at the initiation of motor projection systems, are simultaneously active, the greater will be the tendency for their more central (integrative) correlates to activate each other. This may be a simple assumption, but it has rather broad implications. As well as being an attempt within associationistic theory to incorporate the well-documented gestalt data on perception -- including the basic notions of closure, good figure, 'thing'-perception and the like -- it provides a natural basis for the stable relation between frequency-of-usage of word-form units and their perceptual thresholds, both visual and auditory. It also provides psycholinguistics with what I believe is a crucial distinction -- between words as meaningless forms (sensory and motor integrations) and words as psychological units of meaning (by virtue of their semantic and grammatic coding)." (p. 498)

Osgood's description of his three-stage mediation-integration model follows:

> "On the input side, the lowest level, which I shall call <u>sensory</u>, begins with the receptors and ends with sensory signals at the termini of the projection systems, providing a faithful mirror of 'what is.' The second level, which I shall term <u>perceptual</u>, begins with these patterns of sensory signals and ends with the most probable integration of their more central correlates as determined by redundancies in past experience -- thus, a mirror of 'what ought to be.' The third level, which I shall call <u>meaningful</u>, begins with these meaningless sensory integrations and ends with the most probable representational mediation processes

> with which they have been associated -- a mirror of 'what it signifies' in terms of past experience with behavioral outcomes. Similar analysis of behavioral output yields _execution_ (projection), _skill_ (integrational), and _intention_ (meaningful) levels.
>
> What now requires some explication is the integration level. Let me borrow, rephrase, and simplify a notion developed by Hebb (1949) in his analysis of cell assemblies and phase sequences, and call it the Integration Principle: _The greater the frequency with which stimulus events (S-S) or response events (R-R) have been paired in input or output experience of the organism, the greater will be the tendency for their central correlates to activate each other._ One critical variable here is redundancy among input or output events; another is frequency; yet another is temporal contiguity. But I think this is all -- motivation and reinforcement seem to have nothing to do with the formation of S-S or R-R integrations." (p. 741)

This recognition of several organizational levels in a general model could provide a point of departure for more explicit descriptions which would be necessary for instructional purposes. A similar analysis, somewhat less general, in the sense of being oriented toward serial-task learning, has been done by Greenwald (1970). He addressed himself to the role of sensory feedback of a particular kind, intrinsic sensory feedback, in the development of internal control over serial actions.

Sensory Feedback Mechanisms in Performance Control

Greenwald (1970) discussed the role of sensory feedback in four (S-R) mediating mechanisms: (1) serial-chaining (SC), (2) fractional anticipatory goal responses (r_G-S_G), (3) closed-loop (CL) and (4) ideo-motor (IM). He restricted his analysis to non-verbal mediating mechanisms, to the performance of learned skills (in distinction to classical conditioning) and

to his definition of intrinsic sensory feedback. According to his definition, intrinsic sensory feedback may be either interoceptive or exteroceptive, provided that, in the latter, no additional external mechanism is operating, such as an experimenter delivering verbal reinforcements.

1. The first mediating mechanism he discussed, serial-chaining, is considered to be involved in "learning to perform any routinized series of responses such as a musical melody" (p. 75). Here, a correct performance consists of a series of specific responses corresponding to the series of notes in the melody. Control over the performance is transferred during learning from situational stimuli, e.g., printed musical notation, to stimuli produced by the preceding performance. At an intermediate stage, "playing a given note is consistently preceded not only by reception of the situational stimulus to which performance is already conditioned, but also by reception of stimuli produced by performance of the preceding series of notes" (p. 75).

After reviewing studies involving this mechanism, Greenwald concluded "it seems fairly well established that the serial-chaining mechanism is not always essential to the control of performance for which the originally controlling sensory modalities have been eliminated" (p. 77). He concluded it is possible that a "motor program" is learned which is capable of guiding routinized performance in the absence of feedback of response-produced stimuli. (For example, highly skilled performances may occur too rapidly for response-produced sensory feedback to be effective.)

2. The fractional anticipatory goal response mechanism adds the idea of sensory feedback from an <u>anticipated</u> response, as a mediator of performance, to the serial-chaining mechanism. The anticipated response is

the final goal response. The assumption is that fractional portions of the final, or goal response, in an instrumental sequence can "short circuit" to the beginning of the sequence without disrupting the sequence.

Greenwald's review of pertinent studies suggested that performance mediation by fractional anticipatory goal responses has not been conclusively demonstrated as a better alternative explanation for observed outcomes than non-specific facilitative processes.

3. In the closed-loop mediating mechanism, the performer is presumed to have stored a representation of what sensory feedback from a correct performance <u>should</u> be. He compares incoming sensory feedback from his responses with this "image," and uses the error signals to guide corrective actions. This is the servomechanism model which has been proposed and discussed by a number of theorists (e.g., Mowrer, 1956; Miller, Galanter and Pribram, 1960; Adams, 1968; Anokhin, 1961). Greenwald maintained that it should be possible to account for corrective actions in conditioning terms, rather than appealing to unspecified sources of these responses. Consequently, his proposed closed-loop mediating mechanism includes the assumption that specific responses are conditioned to specific error stimuli through practice with a correction procedure in which "a reinforced (i.e., correct) response is likely to occur immediately following an erroneous one" (p. 80). In terms of a conditioning analysis, this reinforcement would establish a conditioned bond between stimuli produced by the preceding error and the appropriate corrective action. In this ,, the learner might acquire a repertory of corrective actions to specific error stimuli.

Greenwald maintained that this conditioned error-correction performance mechanism makes it unnecessary to assume that the learner uses

images of correct feedback to direct the selection of error-correcting responses, for tasks involving predictable target motion, such as the rotary pursuit task. However, if conditioned error-correction is a valid explanatory principle here, it does require that feedback from <u>incorrect</u> responses be involved in the control of performance. This is an important difference between the closed-loop and the serial-chaining mechanism, in which feedback from <u>correct</u> responses is essential.

Greenwald found evidence in the literature to support the conditioned error-correction explanation. Nevertheless, he agreed that there may be some closed-loop performances in which images of the correct responses are necessary, citing as an example a musician giving a solo performance in which there is no external reference. Greenwald concluded that "it is reasonable to interpret behavioral servomechanisms as being acquired through stimulus-response conditioning in which specific correction responses are conditioned for feedback stimuli from specific erroneous responses" (p. 83).

4. The ideo-motor performance mediating mechanism is based on the assumption that a current response is selected on the basis of its own anticipated sensory feedback, which may become a discriminative signal for performance of the corresponding action. The ideo-motor mechanism has a long history in psychology, having been discussed before the turn of the century by James (1890) and Lotze (1852). It was discarded by early behaviorists, but has returned again.

The ideo-motor mechanism, like the others Greenwald discussed, is considered to be acquired by conditioning. The stages of acquisition are (a) repeated experiencing of the situational stimulus-response, response-generated sensory feedback, (b) conditioned anticipatory images of response

feedback, (c) these images become anticipatory to actual performance, and (d) responses in the instrumental sequence become conditioned to their anticipatory images, so that each element of the representative sequence exerts discriminative control over its corresponding response.

Greenwald cited positive evidence for the ideo-motor mechanism from Luria's (1961) investigations of the development of voluntary regulation of performance in children, and from correlations between thoughts of movements and electromyogram recordings of movements of the effectors (Max, 1935, 1937).

Greenwald discussed the role of the ideo-motor mechanism in the control of novel, skilled athletic performance, and of verbal behavior. He maintained that the combination of basic movements into skilled action sequences in motor skills may be compared to the combination of parts of speech into meaningful sentences. "Just as sentences are meaningful only when the parts of speech are combined grammatically, the golf swing is skillful only if its parts are sequenced within certain formal restrictions" (p. 92). He introduced the terms "programming" or "planning" to designate a stage in the preparation of a complex performance at which response images are organized into an appropriate sequence.

He considered verbal mediation to be a higher-order system for symbolic representation of response images or combinations of them. Thus, the word "ball" would provide access to "a family of ball-relevant responses..." as well as abstracting the common properties of a variety of objects classified as balls. Verbal response mediators would evoke appropriate lower-order, response-image mediators. Some words would have a response-direction function ("grasp," "throw," "kick,") and others a stimulus-elaboration function ("light," "ball").

Greenwald pointed out that none of the mediating mechanisms he described is necessarily an invariable component of skilled performance. Some skilled actions can be performed after apparent total deafferentiation of relevant feedback modalities (Taub and Berman, 1968) or otherwise in the absence of feedback (Keele, 1968). Also, there may be a large class of skilled actions that are so automatically attached to their external stimuli that ideo-motor mediation is unnecessary.

Cognitive Theory

The arguments between associationists and cognitive psychologists are well-known. They are loudest when members of the two groups meet to discuss the same topic, (e.g., Kleinmuntz, 1966; Dixon and Horton, 1968). Mandler (1962) characterized the differences between their general viewpoints as follows:

> "The distinction between associationist and cognitive views may be described as a difference between a topographic and a categorical response definition. While the associations of the associationistic schools are usually considered to be between discrete events in the environment (the stimuli) and topographically well delimited and discrete events associated with the organism (the responses), the cognitive theorist is more likely to talk about formal categories of behavior, giving relatively less attention to the topographic aspects of the behavior classed within those categories. The important questions are: Do organisms learn generalizable, but discrete, responses in specific situations or are rules of behavior, maps, or schemata laid down which connect various behaviors and environmental inputs? Do organisms learn what to 'do,' or do they learn 'what leads to what?'" (p. 415)

Neisser (1967) undertook a comprehensive survey of cognitive psychology in which he followed research on cognitive processes upward in the vertical

ERIC

hierarchy of organization, "from the organs of sense, through many transformations and reconstructions, through to eventual use in memory and thought" (p. vii).

We will attempt to extract from Neisser's survey those concepts which are representative of this viewpoint. The cognitive theorists maintain that the world of experience is produced by the man who experiences it; knowledge of the world must somehow be developed from the stimulus input; cognitive processes that do this surely exist; and that this is the basic reason for studying them.

Cognitive psychologists argue against the Reappearance Hypothesis, the notion that information about the past is somehow preserved in memory and reappears "before the footlights of consciousness at periodical intervals" (James, 1890, p. 236). Instead, they maintain that remembering depends on active, constructive processes. In this sense, all learning is response learning; learning motor skills includes overt movements, learning at a symbolic level does not, although EMG potentials in appropriate muscle groups may occur. Memory consists of traces of prior processes of construction. Memory stores traces of earlier cognitive acts, which are not simply revived or reactivated in recall. The traces are, instead, used as information to support new construction. Neisser stated that:

> "The cognitive approach to memory and thought emphasizes that recall and problem-solving are constructive acts, based on information remaining from earlier acts. That information, in turn, is organized according to the structure of those earlier acts, though its utilization depends also on present circumstances and present constructive skills. This suggests that the higher mental processes are closely related to skilled motor behavior." (p. 292)

ERIC

Problem-solving and deliberate recall are considered to be advanced forms of skilled behavior that have grown out of earlier established forms of flexible adaptation to the environment, with the difference that mental activities are far less dependent on the immediate past (the preceding response) that simple motor skills. Neisser pointed out that what appears to be "simple associative revival of earlier responses" may actually be "complex processes of search and construction." In this sense, remembering is a form of problem-solving.

Neisser used the concept of an executive routine in computer programs to account for the organism's selective use of cognitive structures when engaged in such higher mental activities as problem-solving.

> "The processes of remembering are themselves organized in two stages, analogous to the preattentive and attentive processes of perception. The products of the crude, wholistic, and parallel 'primary processes' are usually elaborated by the 'secondary processes,' which include deliberate manipulation of information by an active agent. An analogy to the 'executive routines' of computer programs shows that an agent need not be a homunculus. However, it is clear that motivation enters at several points in these processes to determine their outcome. Thus, an integration of cognitive and dynamic psychology is necessary to the understanding of the higher mental processes." (p. 279)

A large part of Neisser's book was occupied with the survey and analysis of research on what he called primary processes. His stimulating treatment of these topics should be read by everyone. It is possible here only to present an overview of his viewpoint, which is best presented in his own words:

> "(1) Stored information consists of traces of previous constructive mental (or overt) actions.

(2) The primary process is a multiple activity, somewhat analogous to parallel processing in computers, which constructs crudely formed 'thoughts,' or 'ideas,' on the basis of stored information. Its functions are similar to those of the preattentive processes in vision and hearing. Its products are only fleetingly conscious, unless they undergo elaboration by secondary processes.

(3) The secondary processes of directed thought and deliberate recall are like focal attention in vision. They are serial in character, and construct ideas and images which are determined partly by stored information, partly by the preliminary organization of the primary processes, and partly by wishes and expectations.

(4) The executive control of thinking in the secondary process is carried out by a system analogous to the executive routine of a computer program. It is not necessary to postulate a <u>homunculus</u> to account for the directed character of thought.

(5) The secondary processes themselves are mostly acquired through experience, in the same way that all other memories -- which also represent earlier <u>processes</u> -- are acquired.

(6) Failures to recall information which is actually in storage are like failures to notice something in the visual field, or failures to hear something that has been said. The executive processes of recall may be directed elsewhere, either deliberately or because of a misguided strategy of search; they may also lack the necessary constructive abilities altogether." (p. 303)

<u>Comment</u>

The associationists use the "conditioned bond" as the primitive in their theories, and maintain that contiguity is the necessary and sufficient condition for the initial, temporary formation of these bonds (Estes, 1970). The cognitive psychologists' primitive is the "cognitive act," which leaves

traces in memory. These traces are used as information to guide recall, which is considered to be reconstruction of cognitive structures. According to this view, all learning is "response" learning (Neisser, 1967, p. 285).

If we read these theorists correctly they are all saying that learning results in the progressive development of abilities to cope successfully with more and more complex stimulus patterns by more and more complex response patterns, without relying on external support. All of these theorists hypothesize that the internal processing operations which replace external support are hierarchically organized in several levels.

There must be compelling reasons for a common conclusion that there is a vertical structure of several levels of organization of internal processing operations. The organization of the mammalian nervous system first comes to mind, with its segmental, intersegmental, and suprasegmental reflexes. The possible levels of organization of motor control have been suggested by Elliott (1969) in the following picturesque analogy:

> "Let the body represent a belligerent nation, the muscle fibers being the army, and the lower motor neurons the field officers. The orders given the troops (effectors) by the officers, while simple in themselves, are the final sum of complex influences bearing on those officers.
>
> Reflex arcs might be compared to field manuals directing routine maneuvers, for self-preservation or tactical advantage, by individual military units. The units might be small and local or large and widespread -- as in the myotatic or the Magnus reflexes discussed below. Natural inclinations can be overridden by higher authority, as when troops are designated for suicide missions -- flexor reflex can be voluntarily inhibited in spite of pain.

> <u>Reticular centers</u> would represent army services in control of subordinate but vital upkeep such as procurement, transport and, above all, communications -- control of respiration and heartbeat, and relaying of messages from higher levels. If these services go wrong, the fighting army is disabled.
>
> The <u>vestibular system</u> rather inaccurately corresponds to a diplomatic service which ensures that military operations are conducted in accord with international law -- in this case the great laws of gravity and momentum. In a community as highly organized and self-assured as the human body, recommendations of this service are frequently disregarded.
>
> The <u>extrapyramidal system</u> might be considered a sort of civil service, co-ordinating and allocating the routines of national effort. Like all such bureaucracies, it tends to be stereotyped and inflexible unless regulated or by-passed by higher authority. It seems to be in control of complex but more or less rhythmic, 'instinctual' behavior such as preoccupied walking.
>
> The <u>cerebellum</u> is the general staff or 'Pentagon' of the brain. Drawing on tremendous files of accumulated experience and 'plans,' it manuevers and deploys the armed forces with widespread precision according to any practical requirement of national policy. In other words, it co-ordinates but does not initiate discharge of the motor pool.
>
> Finally, the <u>cerebral cortex</u> represents the legislature that decides what is to be done in the light of established policies and objectives and of a continuous influx of data from the field of action and from other official levels. Properly, it alone has the final authority in such decisions; but, if it lets decision go by default, other levels may take action on their own responsibility -- much as in human affairs." (pp. 238-41)

Secondly, ontological development is a mixture of maturation and learning which propels the organism from helpless infancy toward progressively more powerful abilities and less dependence on external guidance. Theorists are beginning to recognize the critical importance of the early developmental period of "slow learning" in establishing a substrate for

ERIC

later learning (e.g., Hebb, 1949; Gagne, 1968). Estes (1970) remarked on the importance of this period as follows:

> "During this period recurring perceptual and motor patterns become integrated through multiple associative learning into higher units, thus preparing the way for the facile, all-or-none learning characteristic of the mature individual. Analyses of factors involved in the development of 'reading readiness' have demonstrated progressive improvement over the ages of four to eight years in ability to recognize transforms of critical features of stimuli, for example, letter-like forms, which appear in printed material (Gibson, 1965). Impoverishment of a child's early environment, including especially any major restrictions on play activity or lack of feedback from older individuals with respect to vocalizations, must be expected to retard severely this important process of development of behavioral units and thus in turn to restrict the range of situations in which the individual could be expected to manifest normal learning rates in later life." (p. 35)

> "Except perhaps in infancy, a great part of the variance in rates of learning between individuals must be attributable to differences in the results of past learning. Observed rates of learning in most situations, we now realize, depend to a major extent upon habits or strategies of selective attending, seeking of information, coding and recoding of stimulus information, rehearsing, and the like, and the manner in which these are organized. Individual differences in these habit systems may indirectly reflect differences in capacities, but they must also be strongly determined by variation in motivational systems and in previous opportunities to learn. Thus, Gagne (1968) speaks of the 'cumulative-learning' hypothesis of intellectual development. New learning at any age depends to a major extent on the recombining of previously acquired discriminations, behavior sequences, principles, and concepts." (p. 31-32)

In his discussion of the ideo-motor mechanism, Greenwald (1970) also made it clear he was talking about an extended period for its development:

"Ideo-motor learning, ... may quite reasonably be conceived as a process that is based on thousands of learning experiences, spread over the early childhood years, for each of the body's basic voluntary movements -- a process that may require, for example, many hours spent by a child in his crib viewing the movements of his hands, hearing the sounds of his voice, etc." (p. 91)

A third reason for this common assumption of a hierarchical organization is the progressive control the learner gains over his performance while learning serial tasks. Starting somewhere, usually above the fully-instructed baseline, he continues to achieve less dependence on external instruction. It is reasonable to infer that the internal processing operations involved have become progressively more complex. Furthermore, as this learning continues into overlearning, performing the learned task demands less of the performer's attention. Evidently, the processes which guide this performance have become so well organized that some internal resources are freed from monitoring the performance. The components of the required performance evidently are managed in larger chunks at a time; possibly there has been a great deal of S-S and R-R integration.

Fourth, the difficulty of serial-tasks is related to their complexity in terms of the number of different operations, different number of choice points, number of different discriminations, _etc_., involved. This is recognized by industrial engineers, who simplify assembly line tasks by breaking them up into components, reorganizing them into groups of similar actions, reducing visual search requirements, _etc_. This also was at the heart of the programmed instructionists' concern over "small steps" between successive frames.

It appears, then, that these theorists are telling us what is learned is a vertical hierarchy of internal processing operations, with each level

being an abstraction from and an integration of the next lower level. As we proceed upward, we find increasing freedom from the immediacy of the present. Representational processes allow us to create our own world. The symbolism of language allows us to manipulate representations of events long past, or anticipated in the future. At these higher levels we move across past, present, and future more or less at will. Higher level processes operate on representational processes to generate sequentially organized behavior; verbally facilitated thought, which is not necessarily tied to the present, and motor performance, which necessarily is.

Gagne saw eight types of learning in this vertical organization:

> "(1) signal learning -- the establishment of a conditioned response, which is general, diffuse, and emotional, and not under voluntary control, to some signal; (2) S-R learning -- making very precise movements, under voluntary control to very specific stimuli; (3) chaining -- connecting together in a sequence two (or more) previously learned S-R pairs (4) verbal association -- a subvariety of chaining in which verbal stimuli and responses are involved; (5) multiple discrimination - learning a set of distinct chains which are free of interference; (6) concept learning -- learning to respond to stimuli in terms of abstracted properties like color, shape, and number; (7) principle (rule) learning -- acquiring the idea involved in such propositions as 'If A, then B' where A and B are concept -- that is, a chain or relationship between concepts, internal representations (of concepts) rather than observables being linked; (8) problem solving -- combining old principles so as to form new ones." (Scandura, 1970, p. 518)

Gagne (1968, 1970) more than anyone else, has been concerned with translating the "bare bones" kind of vertical hierarchy, illustrated here by Osgood's model, into prescriptions useful to the educator. He used the term "intellectual skills" to refer to internal processing operations related to content, and presented examples of learning

hierarchies in elementary mathematics, science, English, and a foreign language. He maintained that intellectual skills, in distinction to verbal information, are what tend to remain with the individual over long periods of time. Gagne (1970) pointed out that (in our current state of knowledge about intellectual skills), in most cases:

> "these structures represent hypotheses about the arrangement of intellectual skills within each subject that have not been verified, although they are capable of verification. Accordingly they do not represent final answers to questions of subject matter structure, but only an initial suggestion of such an answer." (p. 245-246)

Guilford's (1967) monumental work on the structure of the intellect was a psychometric approach to the identification and categorization of these internal processes, which resulted in a "dictionary of factors" classified under three major headings; operations, products, and contents. Guilford (1968) has discussed the implications of this structure for education.

Verbal behavior was another common concern of these theorists. All of them recognized language as a higher-level mediator. Verbal behavior is of interest to us because it is structured serial behavior -- speaking is a kind of abstract serial task -- and because language clearly is the pre-eminent learning tool available to humans. Any adequate theory for training must include the role of language both for learning to perform and for learned performance. Greenwald (1970) reminded us of Pavlov's second-signal system, and noted similarities in verbal and motor behavior, comparing the construction of a sentence to the "construction" of a golf swing. To Greenwald, in the ideo-motor mechanism:

"An extensive repertory of response images constitute, a 'language' in which basic voluntary movements are represented. This view allows the verbal language to be regarded as a higher-order system for symbolic representation of response images or combinations thereof. The variable sequencing of words allowed by the generative rules of the verbal language thus greatly multiples the potentiality of performance flexibility already allowed by the lower-order response image language." (p. 93)

Neisser devoted several chapters to an analysis of speech perception, auditory cognition, active verbal memory, and the structure of sentences. In the analysis of sentence structure, he related concepts in linguistics to concepts in cognitive psychology, emphasizing the close relationship between the rhythm of speech, the structure of language, and the listeners' internal representation (Neisser, 1967, p. 262).

Osgood was concerned with psychological theories for "rendering comprehensible the way human beings understand and create sentences," when he presented his three-stage mediation-model, described in the first part of this section.

The "sentence generator" must have some resemblances to the "serial-task generator;" sentences have structures resembling in some ways serial-task structures. If we understood the central processes which create sentences we very likely would thereby know more about serial-task generators and transfer of training. Neisser quoted Chomsky's (1964) comment related to this:

"... a mature speaker can produce a new sentence of his language on the appropriate occasion, and other speakers can understand it immediately, though it is equally new to them. Much of our linguistic experience, both as speakers and hearers, is with new sentences; once we have mastered a language, the class of sentences with

ERIC

which we can operate fluently and without difficulty or hesitation is so vast that for all practical purposes (and, obviously, for all theoretical purposes) we can regard it as infinite ... a theory of language that neglects this 'creative' aspect of language is only of marginal interest." (p. 244)

Even repetitive serial tasks are never performed in exactly the same way. In many cases, task goals can be achieved in any of many different ways; the performer "steers toward the goal" not unlike Lashley's rat walking, rolling, or crawling through the maze, never repeating exactly the same motor pattern. It may be that a really satisfactory theory for transfer of training will depend upon understanding the "deep structure" of sentences, a problem to which transformational grammar is addressed.

The sentence generator and the serial-task generator are serial-behavior generators. This reminds us of the temporal dimension of behavior. Osgood (1963) described levels of organization of behavior and the temporal elaboration of behavior in this way:

"It will be useful for us to think in terms of two quite different types of hierarchies: sequential hierarchies (horizontal, left-to-right), relating antecedent to subsequent events; and simultaneous hierarchies (vertical, up-to-down), relating subordinate events to supraordinate events. The former are clearly Markovian or probabilistic in nature; the latter clearly are not.

Viewed in the abstract, there are two different kinds of sequential hierarchies, convergent and divergent: A pure convergent hierarchy exists when multiple antecedent events are associated with a single subsequent event; a pure divergent hierarchy exists when a single antecedent event is associated with multiple subsequent events. As we know from transfer and interference studies, convergent hierarchies are facilitative whereas divergent hierarchies are competitive. But behavior does not transpire in the abstract, of course, and in practice convergent and divergent hierarchies involving the same sets of events operate simultaneously.

ERIC

... the notion of simultaneous, vertical hierarchies of units within units within units has been about as foreign to psychologists as the notion of probabilistic sequential hierarchies has been to linguists." (p. 741)

A "serial-task performance generator" might require the categories of internal processes represented in Figure 2.

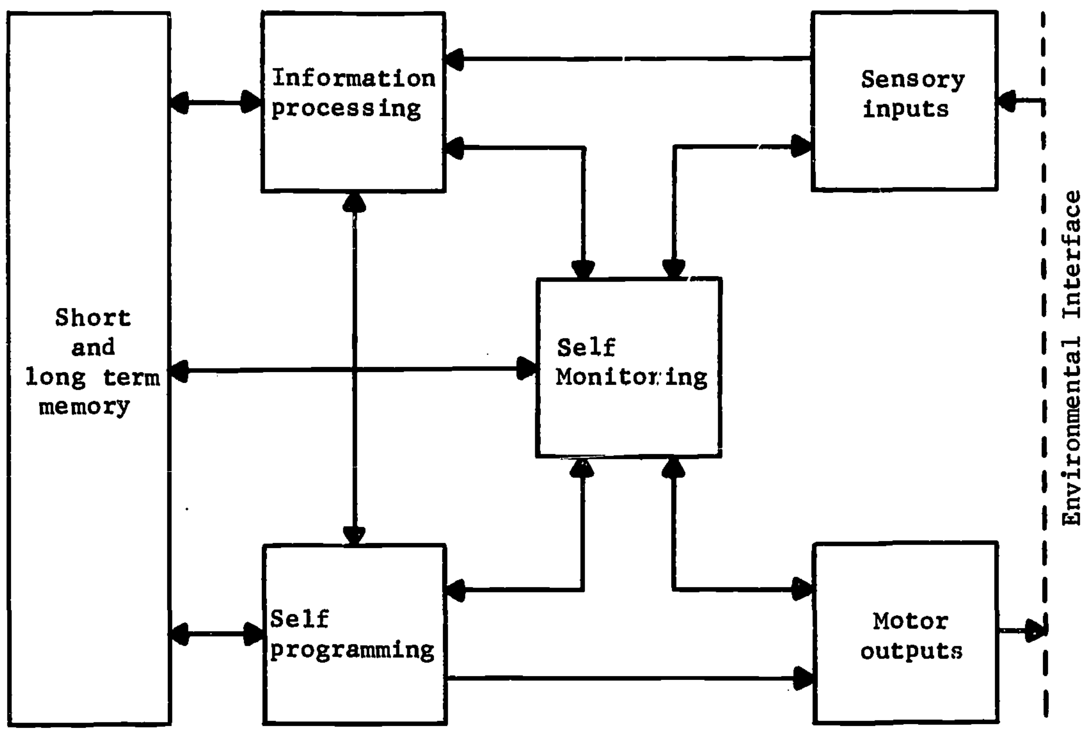


Fig. 2. The organization of serial-action performance.

Two "control function" categories are self-programming and self-monitoring. Greenwald (1970) alluded to self-programming, a term perhaps first used by Miller, Galanter, and Pribram (1960). A performer plans ahead to some extent, anticipating the goals to be accomplished, and

thinking about how to accomplish them. He may visualize only a general procedure before he begins, and then fill in the detailed instructions as he goes along. Self-monitoring includes internal processing operations which allow the performer to identify himself as an entity, to "stand aside and watch himself perform," and to relate his estimates of how well he is doing to internal and external standards, for example, the performance of his peers. Self-monitoring also includes time-sharing of attention among the different, required components of performance. There are assumed to be large numbers of processes in each of these functional categories. Only a subset of processes in each category may be used for performing particular tasks, and these processes may be organized in different ways.

The conception of sentence generators and serial-task generators as mechanisms for generating "new sentences" and "new serial-task performances" is a reminder of the power of rules as the internal guidance for elaborating temporal sequences. Gagne maintained that "the kind of human capability that is acquired in problem solving seems to be a capability of applying a rule to any number of specific instances" (in Kleinmuntz, 1966, p. 131).

Several theorists recently have addressed the question of the nature of these rules. Scandura (1970) proposed a precise formulation of the notion of a rule in terms of sets and functions, in a set-function language (SFL). In his view, "a rule can be denoted by a function whose domain is a set of stimuli and whose range is a set of responses" (p. 519).

He argued that the psychologists' concept and association are special cases of this formulation:

"A concept can be represented by a function in which each stimulus is paired with a common response, while an association can be viewed as a function whose defining set consists of a single S-R pair." (p. 519)

A function, in turn, Scandura defined as a set of ordered pairs or as an ordered triple. He pointed out that the class of S-R behaviors that can be generated by a rule might best be characterized by the first part of the definition, while the construct of a rule would conform to an ordered triple, involving a set of inputs, a set of outputs, and a connecting operation. Thus, he defined a rule as:

"An ordered triple (D, O, R) where D refers to the determining property of the stimuli, and O to the combining operation or transformation by which the derived properties (of the responses, R) are derived from the properties in D." (p. 520)

Scandura maintained that accounting for the essential characteristics of behavior on structured tasks is done better in terms of rules than in terms of mediating responses and response-produced stimuli, because mediational accounts of such behavior tend to be ad hoc, complex, and cumbersome. He asserted that it also is necessary in these mediational accounts to assume that associations can act on other associations. He discussed the role of rules in decoding and encoding, symbol and icon reference, and higher-order relationships. He then discussed the considerations for operationally defining what rule is learned, pointing out that this is tied to transfer of training. He recognized that it is impossible on logical grounds to define in terms of performance what particular rule is learned in any unique sense. There are many routes to the same end; which of a set of rules is applied will depend on what

ERIC

the organism is trying to do. But he pointed out, if the goal of a performance is known in a given stimulus situation this amounts to specifying a class of rule-governed behaviors, which partitions the set of rules the performer has learned into two mutually exclusive subsets; rules which can be used to attain the goal and rules which cannot. But, rules frequently have an infinite number instances and it is impossible to test for the acquisition of more than a relatively few. Scandura stated that what seems to be needed is a definition which takes into account all feasible underlying rules. Such a definition can be given by specifying what is learned up to a class of rules:

> "Thus, given a class of rule-governed behaviors and that a particular stimulus in that class elicits the corresponding response, 'what is learned' can be defined as that class of rules whose denotations all include the given S-R pair. This definition may be interpreted to mean that at least one of the rules in the class has been used in responding to the test item.
>
> The problem remains of adapting the definition to include any number of test instances. Fortunately, this can be accomplished directly. Given a particular rule-governed class, $\underline{n}$ test instances, and a performance capability summarized by success on $\underline{m}$ of the $\underline{n}$ test instances ($\underline{m} \leq \underline{n}$) and failure on $\underline{n} - \underline{m}$ of these test instances (and assuming that no learning takes place during testing), then 'what (rule) is learned' is defined as that class of rules which provides an adequate account of the test data. In particular, a rule is included in the class if and only if its denotation (i.e., set of S-R instances) includes all of the test instances on which success is obtained, but none of those involving failure. That is, the characterization of 'what is learned' includes all of the rules which might possibly account for the fact that S succeeded on some of the items but not others." (pp. 528-29)

Restle (1970) was concerned with rules that might be used to learn serial patterns, which, he pointed out, are involved in many forms of

human behavior, e.g., walking, driving an automobile, speaking, playing the piano, or playing chess. He reminded us of the difficulties of studying this behavior in the laboratory: the set of elementary behaviors may be too large; the occasion for the behavior may be difficult to control; the component responses may have no separate environmental effects that make them convenient to record; and many meaningful behaviors may be so overlearned that any separate intrinsic structure may not be distinguishable from the effects of overlearning which might tend to smooth and integrate an arbitrary sequence of movements.

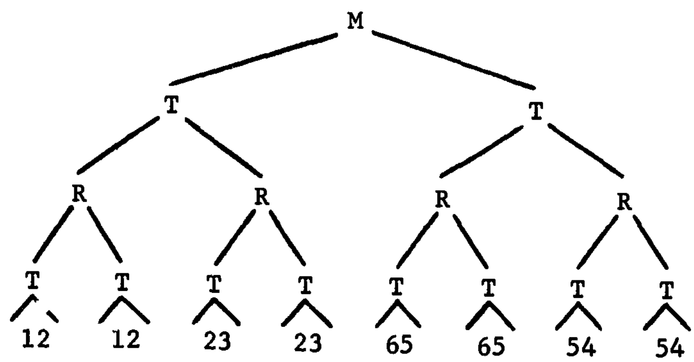
Restle used a series of lights with corresponding switches for one type of serial pattern learning task. He found that college students who attempted to learn sequences of 32 binary events presented 20 times exhibited regularities in their response data which, in terms of error profiles, were in good agreement with the hypothesis that:

> "S should have the most difficulty in learning and correctly predicting the highest order transformations in the sequence, and should find the lowest order transformations easiest." (p. 488)

Restle proposed a "recursive E-I theory" in which E is the set of elements or events forthcoming, and I is the set of intervals leading from one event to the next. From this he developed a theory of structural trees in which:

> "The general idea of a truly hierarchical model for sequential learning is that the total sequence 'concept' or system of rules serves to generate a sequence of certain elements. Each element is a rule system, which in turn can generate other elements. The elements of any rule system can be other rule systems, or (at the tips of the branches of this tree) may be specific events." (p. 486)

He used the algebraic notation of compound functions to describe generation of these structures. For example, M(T(R(T(1)))) describes the operations of concatenation and transition involved in generating long binary patterns. T stands for transposition, R means repeat, M means mirror image, and I is the size of the interval. The above expression describes a tree of the following form (p. 487):



Restle discussed right-branching trees "at each level the tree breaks down into two parts -- to the left, a single element or small tree built on a particular element, to the right a subtree with the same property as the parent tree" (p. 490), and summarized the structural theory of serial pattern learning as follows:

> "Any sequence can be rewritten as follows:
>
> $$S \longrightarrow A + B \qquad (1)$$
>
> where "+" signifies concatenation.
> If F is any transition function and S any sequence to which it applies, then
>
> $$F^n(S) \longrightarrow S + F^{n-1}(f(S)) \qquad (2)$$
>
> Furthermore,
>
> $$F^o(S) \longrightarrow S \qquad (3)$$

> With this system, the structural tree of any regular sequence, using any mixture of binary and right-branching trees, can be constructed. Furthermore, using the first rule (Equation 1), it is possible to give an account of non-homogeneous trees, namely those requiring use of such an arbitrary rewriting rule." (p. 492)

Restle summarized results of experimentation in which these ideas were applied. Restle and Brown (1970) found that different versions of the same pattern, e.g., transposed or mirror image, contained the same difficulties for the learner. The number of errors at each location and the most frequent errors were found to be the same in these different versions. They found that subjects tended to divide patterns into parts, a common resulting pattern of data including more errors at the beginning than at the end of a subunit, and a large number of errors right after a subunit, where presumably the organizing principle of the subunit was extended too far.

Restle demonstrated that the theory of structural trees applies to the analysis of highly patterned music by analyzing the first four measures of Bach's two-part Invention No. 1, and pointed out it is possible to study the learning of a simple musical piece from the point of view of serial pattern learning. The tree structure could be used to predict the difficult locations in the piece, and these predictions could be checked empirically.

Rigney and Towne (1969) were concerned with the structure of serial-tasks of the sort encountered in goal-oriented work. Rules were developed for representing this structure in terms of the overall goal, the sequence of subgoals, and the patterns of actions to be accomplished for attaining each subgoal. The notation for list structures was used to

represent the hierarchical organization of the task structure. This approach had the advantages that irregular structures could be represented as well as regular ones, and that actual tasks encountered in the world of work could be described in this way. The elements involved were the goal name (GN), the sequence rules (SEQ, ANY, or ALL), and the action name (A,B,C,...). The sequence rules referred to the order in which actions and higher level units were to be accomplished. Thus, SEQ meant do all following actions and higher order units in the exact sequence specified; ANY meant do any one of the actions or higher order units specified; and ALL meant do all of the specified actions or higher order units, but do them in any order. One might have as many levels in the hierarchy as needed to represent the task.

It would be possible that the learner could learn the rules for representing task structures and apply them in a recursive fashion. Thus, each subgoal unit requires that the performer know what the subgoal is, the set of permissible actions to attain it, and the sequence constraint on performing these actions. (He also needs to know how to ascertain whether or not he has indeed accomplished the subgoal, i.e., if he has made an error or not, before going on to the next unit.) He may eventually learn to generate serial task performances which are effective in accomplishing goals, by recursively applying rules of this sort. This would be analogous to generating sentences.

It is of some interest that the computer program written to track subjects performing serial tasks operated on list structures of the sort described above with recursive functions written for the purpose in a list-processing language. It often occurred to the authors of the program while it was being developed that there were interesting comparisons to

ERIC

be made between the way a program like this operates and some aspects of human thought processes. At higher levels of the program, one function (rule) could call another function (rule), which could call another, etc., as needed to accomplish a particular overall goal, and at lower levels a recursive function could "take a list apart, operate on each selected portion in turn, and put it back together again." No claim was made that a program of this sort actually simulates human thought processes. What was significant was the power that this approach gave the investigator to deal with meaningful, real-world tasks, and the insights it provided into the possible ways a "serial-task generator" might work.

In his discussion of organizational factors in memory, Bower (1970b) also noted these similarities. He described a possible list-processor, a cognitive simulation program, for processing digit lists, which included a push-down list (he called Most Recent List), a mechanism dear to the hearts of LISP programmers. He concluded that:

> "hierarchical list-structures provide a natural language in which to represent and theorize about our results on memory for grouped digit series." (p. 43)

SECTION IV. HOW IS IT LEARNED?

Individual differences in rate of learning the same material suggest there are differences in learning processes different students can bring to bear on the task of learning. Theorists are beginning to recognize the importance of these processes, and of the period in early life for their development (Estes, 1970):

> "Observed rates of learning in most situations, we now realize, depend to a major extent upon habits or strategies of selective attending, seeking of information, coding and recoding of stimulus information, rehearsing, and the like, and the manner in which these are organized. Individual differences in these habit systems may indirectly reflect differences in capacities, but they must also be strongly determined by variation in motivational systems and in previous opportunities to learn." (p. 31)

> "Efforts, however persistent, to train or educate the older retarded individual by means of the teaching and training techniques appropriate to a normal individual of similar chronological age (CA) must be expected to prove largely ineffectual, since they do not compensate for the retarded individual's impoverished repertoire of stimulus and response patterns." (p. 36)

The important question concerns whether the acquisition and use of these processes can be manipulated to improve learning rates. It may be that there is a critical period for acquisition of basic learning facilitators corresponding to critical periods for maturation of physiological mechanisms. Perhaps this psychological development emerges from a substrate of physiological growth processes and depends upon the fact that the organism _is_ growing. It is possible that conditions exist in the central nervous system which are optimum for establishing these basic habits,

ERIC

and which never again exist, at least to that degree, once the critical time has passed. We are reminded of the experiments of Harlow (1970) with infant monkeys, and of Levine's (1960) and other's findings that young animals subjected to stress actually are better able to cope with stress as adults than young protected from stressful experiences.

Estes (1970) remarked on the possibility that neurophysiological mechanisms involved in normal adult learning may fail to develop in the absence of adequate stimulation and activity in impoverished environments in custodial institutions for children. It also is likely that children quickly develop attitudes toward learning in their early experiences with school which may persist for long periods. Children who repeatedly experience failure in school develop aversive reactions to learning which may inhibit the acquisition and use of learning facilitators. A number of critics of the educational system have pointed this out (e.g., Holt, 1964).

Failure to acquire fundamental learning facilitators is one potent source of ineffective learning. Another is the extent of prior learning of related material. Another is the motivational system for learning, the development of which certainly is an important issue (Bond, 1971).

Our interest in this chapter is in examining the possibility that more specific learning facilitators can be identified under the general headings of selective attention, rehearsal, imagery, verbalization, etc., and of exploring their possible roles, in relation to those stages in the learning process which have achieved some degree of acceptance by theorists; entrance into sensory register, storage in short-term memory, consolidation, and storage in long-term memory. Just as "sentence

ERIC

generators" and "serial-task performance generators" must be hypothesized to account for the corresponding behaviors, a "learning generator" can be hypothesized as the mechanism through which learning facilitators operate. Learning is considered to be a special kind of performance, as well as a consequence of performance. The greatest limitation of any human performance is that it must be serial in nature; limited span of attention and limited effector mechanisms confine humans to "doing one thing at a time." The scope of material that can be taken under consideration, and the scope of action that can be accomplished at one time are both limited by this "serial-processor" characteristic of the organism, (e.g., see Miller, 1956). When learning begins it is as though there is an input tape which is decoded a unit at a time, and an output tape which is punched a unit at a time. As learning occurs, inputs and outputs are dimensionalized, categorized, and organized so that the central mechanisms can deal with increasing stimulus complexity and increasing response complexity by operating on higher-order units.

It is curious that the input side of the learner seems to have been studied more than the output side. The well-known concepts, "sensory register," "short-term store," "consolidation," and "long-term store" apply to getting information in. On the output side, responding depends upon activating particular muscle groups in a particular sequence. This activation is superimposed on a substrate of postural, locomotor, eye-hand coordination, and verbalization patterns which either are "wired in" reflexes or are so overlearned that they function in a similarly automatic way, assisted by intrinsic feedback from receptors in skin, muscles, tendons and joints, and extrinsic feedback from exteroceptors. Much of the

serial-task learning of concern to training must require, on the output side, no more than putting together new sequences of these overlearned response patterns. Where new response patterns must be learned, as in typing, music, and many sports, learning characteristically is much slower, requiring repeated practice sessions extending over long periods of time.

Selective Attention

The development of efficient habits of selectively attending, and the management of selective attention by the learner during learning would seem to involve a variety of factors, some known and some not. It appears that the development of attentional processes initially is intertwined with maturation and early learning.

A prior consideration is the effectiveness of the stimulus event in attracting attention. Capturing and holding the attention of the student is a precondition for transmitting information to him. The stimulus events which are presented must compete successfully with other sets of stimuli, internal and external, for attention. The "surprisal value" (Berlyne, 1960) of the presented stimuli probably is the basic factor in capturing attention.

The pioneering work of Cherry (1953), Broadbent (1952) and Treisman (1964) re-established selective attention as a legitimate research topic. Although the central mechanisms for selective attention are unknown, it is clear the organism decides what it will attend to and what it will reject under most circumstances, and that selective attention is a process at least partially under voluntary control.

Treisman (1969) reviewed strategies and models of selective attention. She distinguished four types of attention strategy:

> "The first restricts the number of inputs analyzed; the second restricts the dimensions analyzed; the third the items (defined by sets of critical features) for which S looks or listens; and the fourth selects which results of perceptual analysis will control behavior and be stored in memory." (p. 282)

Treisman tentatively suggested that the nervous system may be forced to use "whatever discriminative systems it has available" if these are not already fully occupied with other tests or inputs. However, Treisman pointed out that there are many more questions than there are answers in this area.

Evidently an important process involved in the operation of selective attention on incoming information is the prior analysis of the "context and expectations involved in the situation" (Norman, 1969, p. 35). Norman has proposed a model of selective attention in which:

> "Both the physical inputs and the pertinence of information determine what will be selected for further processing. Physical inputs pass through the sensory system and stimulus analyzing mechanisms before exciting their representation in the storage system. Simultaneously, the analysis of previously encountered material, coupled with the history of expectations and the rules of perception, determine the class of events assumed to be most pertinent at the moment. That material which receives the greatest combined excitation is selected for further attention." (p. 34)

What is attended to evidently will be determined by the past history of attending in similar contexts under stimilar motivational conditions which has established "pertinence" values. Estes (1970) describes this

as "the acquisition of habits of selective attention with respect to the stimulus properties which differentiate the members of important classes of objects or events" (p. 36). Thus, the learner in possess on of these habits may very quickly identify those stimulus properties that are pertinent to his goals. An efficient use of selective attention should enable the learner to reject large masses of information typically made available in training situations and concentrate on those particular cues he needs. An individual without these effective habits of selective attention may be distracted by the less relevant information in the situation. A key operation in the determination of "pertinence" or "relevance" is the identification of the goals of the learning. If, for example, the goal is to learn how to write a subroutine to establish and use a random access file on a computer disk memory, it is inefficient first to read through the entire manual of instructions for the programming language in use. Many instructions described there would not have pertinence to the subgoals of this task.

It may be that a major source of difficulty for students whose learning rates are slow is the inability to "separate the signal from the noise" by efficient use of selective attention. Zeaman and House (1967) presented evidence that differences in the probability of attending to relevant dimensions in stimulus discrimination tasks are more important than individual differences in rate of acquisition and extinction in accounting for differences between discrimination learning curves of bright and dull children.

Kagan (1970) has investigated determinants of attention in the infant. He observed general changes in these determinants, from a preference for

attending to objects with high contrast, or that moved, in the first few months; to attending to discrepancies from mental representations of events Kagan called schemas, between three and six months; to attending to events that activated "hypotheses," near the end of the first year. Kagan defined a hypothesis as a cognitive structure which is "an interpretation of some experience accomplished by mentally transforming an unusual event to the form the child is familiar with" (Kagan, 1970, p. 303). Kagan's conclusions regarding the importance for learning of developing habits of selective attention are of particular interest:

> "The influence of contrast, discrepancy, and activation of hypotheses on distribution of attention is probably not limited to the first two years of life. Schools implicitly acknowledge the validity of these principles for older children by using books with contrasting colors and unusual formats and by emphasizing procedures whose aim is to ensure that the child has a relevant hypothesis available when he encounters a new problem. A child who possesses no hypothesis for solution of a problem is likely to withdraw from the task. Many children regard mathematics as more painful than English or social studies because they have fewer strategies to use with a difficult problem in arithmetic than for one in history or composition. The school might well give children more help in learning to generate hypotheses with which to solve problems, and put less pressure on them to accumulate facts.
>
> The principles discussed in this paper are also related to the issue of incentives for acquiring new knowledge. The behaviorist, trying to preserve the theoretical necessity of the concept of reinforcement, has been vexed by the fact that the child acquires new knowledge in the absence of any demonstrable external reward. However, the process of assimilating a discrepant event to a schema has many of the characteristics of a pleasant experience and therefore is in accord with the common understanding of a reward. The central problem in educating children is to attract and maintain focused attention. The central

theoretical problem in understanding mental growth is to discern the factors that are continually producing change in schema and hypothesis. Solution of these two problems is not to be found through analyses of the environment alone. We must decipher the relation between the perceiver and the space in which he moves, for that theme, like Ariadne's thread, gives direction to cognitive growth." (p. 305)

It is possible, then, that three processing steps are involved in getting information into STS from a sensory register (SR). The first process attempts to identify the stimulus event and the second makes a judgment of "pertinence." In the first, schemas and hypotheses are retrieved from LTS, the schemas for matching with stimulus patterns, the hypotheses for relating familiar concepts to the patterns. Kagan's concept of hypotheses seems to imply a third step, answering the question "what do I do about the new stimulus (problem)?", since he maintains that a child who has no hypothesis for solution of a new problem may withdraw from the learning task.

If the stimulus events are identified, then a judgment of pertinence is made, and only if the internal representations of the events are pertinent to the learner's goals are they retained in STS. If the stimulus events are so unusual they cannot immediately be identified, their representations probably also will be retained in STS for further attempts, or until some judgment can be made that the strange stimuli are not an immediate threat, or until the information is pushed out of STS by succeeding events.

If this is so, the practical problems for the learner are to identify stimulus events, to make accurate pertinence judgments, and to decide what to do about the events. A strange word or symbol may block understanding

of a concept. If there are too many unfamiliar words or symbols the learner may simply give up. The instructional technologist could provide external substitutes for schemas and hypotheses. He could formulate the material to be learned in more familiar terms to the learner. Pertinence is judged at least partially in relation to the goals of the learner. In the common situation in training the learner cannot make pertinence judgments very well because he does not know what the ultimate goals of training are. Often he cannot relate stimulus events to the performance that will be required of him later. He should be given a precise statement of goals at the beginning of training, and an overview of the relationships between information and performance that have been identified as important by others. If he knows what is going to be required of him he can make more accurate pertinence judgments.

It would be possible to give learners practice in the operations of identifying, interpreting, and relating stimulus events to goals. In serial-task training, an initial, fully-in[illegible], "walk-through" should give the learner an idea of the performance requirements he will be expected to meet at the end of training, providing some basis for judgments of pertinence of stimulus events presented to prepare him for this performance. As he begins to internalize performance requirements, he will be able to make better judgments of pertinence. Reinforcement would come from successful performance after selectively attending to particular stimulus events.

A related consideration is the development in the learner of the ability to exclude competing stimuli from his use of selective attention in a learning task. The learner must set himself to the task of learning.

The habit of concentration probably requires long and careful nurturing in the face of continual distractions. The distractibility of childhood is only slowly replaced by the ability of adults to concentrate voluntarily on an area of discourse. This development can be characterized as the gradual shift of control over attention from external conditions to internal processes. Magoun (1969) hypothesized that, at a neuro-physiological level, reinforcing mechanisms supply arousal of higher centers after the orienting reflex habituates.

It seems likely that the habit of concentration could be developed through practice. In this context, concentration involves restricting selective attention to content boundaries. Certain kinds of tasks are recognized as demanding concentration: mentally multiplying together multi-digit numbers; mentally tracing the signal flow paths through an electronic equipment; writing a computer program that uses interrelated variables. In these tasks, it is necessary to keep information in and operations going in STS long enough to finish the task.

Consolidation

How consolidation occurs is a subject of much research interest but as yet the nature of consolidative processes is a mystery. Estes (1970) commented on this, and on the possible role of learning facilitators in influencing consolidation, as follows:

> "There is considerable reason to believe that the process of consolidation, or transition to long-term storage, though doubtless modifiable by many conditions, may be initiated following any given learning experience in an all-or-none fashion by some mechanism, as yet unidentified, which is relatively localized." (p. 33)

ERIC

"Most attention tends to be given in the literature to the long-term possibility that functioning of consolidation or storage mechanisms might be improved by drugs or other physiological manipulations. But the more immediate fruits of research in this area, which might yield tangible improvements in learning efficiency on the part of normal individuals as well as the retarded, would seem to be the habits of selective attention and rehearsal and other behavioral tactics that can be developed by training and brought under voluntary control." (p. 34)

In Atkinson and Wickens (1970) discussion of the relations between reinforcement, attention, and memory processes, there is presented an interesting conception of the conditions for consolidation, defined as transfer from short-term storage (STS) into long-term storage (LTS).

Excerpts from this discussion are presented at some length below, since they present a clear expression of how these theorists view these processes in the context of paired-associates learning.

"In many ways our interpretation of reinforcement is quite similar to the ideas of attention that were discussed in the preceding section. Transfer of information to LTS takes place only while that information is resident in STS. Thus, if learning is to take place, the appropriate information must be maintained in STS for some period of time. As indicated before, however, STS is a system of limited capacity, and many potential sources of information are competing for access to it. At the same time that an item is being studied for later recall, processing space in STS is also demanded by incoming stimuli and by other items already in STS. The extent to which information about the item is successfully processed depends on the limitations imposed by the task and on the strategy selected by the subject." (p. 122)

"This description is, basically, an expectancy interpretation of reinforcement, and as such is in the tradition of the ideas set forth by Tolman (1932) and by Brunswik (Tolman & Brunswik, 1935). Essentially, it consists of two components: first, the formation of a prediction (and possibly

> the production of a response) based on the stimulus input and on correlated information retrieved from memory, and second, the comparison of this prediction with subsequent events. It is the result of this comparison that determines whether information about the episode will or will not be transferred to LTS.
>
> As noted in the section on attention, the transfer of information about an external event to STS involves more than simply a transfer from the SR to STS. In particular, a reference to LTS is required in order to generate a pertinence measure, and some of the recovered information will be entered into STS along with information from the SR. This information, along with other information that may be retrieved later from LTS, is used by the subject to select a response if one is necessary. In addition, this information allows the subject to generate an expectation or prediction about the events that will follow the stimulus. Any response that is required is based on this prediction, but the prediction usually is more elaborate than may be inferred from the observable response. When the outcome event in question occurs, it is compared with this prediction. The extent to which the outcome fails to agree with the prediction determines the degree and nature of the study the item receives. Usually, large discrepancies between the prediction and the outcome dispose the subject to apply control processes that maintain the relevant information in STS and induce the transfer of information to LTS. The information which is transferred is primarily associated with those components of the prediction that were most deviant from the actual outcome. The result is to reduce the disparity between the outcome and information now stored in LTS so that if the same stimulus and outcome were to be presented again, the discrepancy would be smaller than the original one." (pp. 124-125)

Perhaps most research on consolidation has been done with animals, since various types of procedures; e.g., shock or drugs, may be used to facilitate or to disrupt memory processes.

McGaugh (1966) reviewed studies of time-dependent processes in memory storage, and concluded that:

"These observations indicate that the long-lasting trace of an experience is not completely fixed, consolidated, or coded at the time of the experience. Consolidation requires time, and under at least some circumstances the processes of consolidation appear to be susceptible to a variety of influences -- both facilitating and impairing -- for several hours after the experience. There must be, it seems, more than one kind of memory trace process (31). If permanent memory traces consolidate slowly over time, then other processes must provide a temporary basis for memory while consolidation is occurring. The evidence clearly indicates that trial-to-trial improvement, or learning, in animals cannot be based completely on permanent memory storage. Amnesia can be produced by electro-shock and drugs even if the animals are given the treatment long after they have demonstrated 'learning' of the task."
(p. 1357)

He presented a description of a "tritrace" memory system, which has been proposed by some investigators:

"A complex picture of memory storage is emerging. There may be three memory trace systems: one for immediate memory (and not studied in our laboratory); one for short-term memory which develops within a few seconds or minutes and lasts for several hours; and one which consolidates slowly and is relatively permanent. The nature of the durability of the long-term memory trace (that is, the nature and basis of forgetting) is a separate but important issue. There is increasing evidence and speculation (20, 21, 33) that memory storage requires a "tritrace" system, and our findings are at least consistent with such a view.

If there are, as seems possible, at least three kinds of traces involved in memory storage, how are they related? Is permanent memory produced by activity of temporary traces (31), or are the trace systems relatively independent? Although available findings do not provide an answer to this question, there does seem to be increasing evidence that the systems are independent. Acquisition can occur, as we have seen, without permanent consolidation, and both short-term and long-term memory increase with time. All this

evidence suggests (but obviously does not prove) that _each_ experience triggers activity in _each_ memory system. Each repeated training trial may, according to this view, potentiate short-term processes underlying acquisition while simultaneously enhancing independent underlying long-term consolidation. Obviously, acceptance of these conclusions will require additional research." (pp. 1357-58)

Lewis (1969) reviewed literature on consolidation in a discussion of sources of experimental amnesia. He concluded that:

"Two properties of consolidation seem to be held by all who have treated the subject and a third and fourth probably are held by a majority. The two universal properties have to do with (a) fixation and (b) the time-bound effect. The two properties that are widely but not universally held concern (c) the permanence of the amnesic disruption and (d) the number of memory stages." (p. 462)

However, Lewis maintained that consolidation theory "is a rather loose set of assumptions that are more or less widely held by most of those who do research on experimental amnesia" (p. 463), and discussed alternative hypotheses and detailed the probable complexities of the processes covered by the term "consolidation." He tentatively proposed that memory fixation (learning) is almost instantaneous with information input (registration) and that amnesic agents have their effects on processes subsequent to fixation:

"There is a great deal going on subsequent to fixation as the learning-performance distinction has always made clear. And there is nothing in the design of amnesia experiments that demands that a response (output) failure be always attributable to a failure to fix the input." (p. 470)

ERIC

We see then, that consolidation is a topic of great current interest in animal research, and that there are differing viewpoints concerning the processes involved. "Learning facilitators" so far tried in these animal experiments have usually been drugs which are not likely agents for use with humans, although McGaugh pointed out that "it has long been known (and ignored) that, within limits, learning is facilitated by increasing the intervals between repeated trials" (p. 1357).

Although theorists disagree about the nature of consolidative processes, consolidation refers to storage of material in long-term store. We assume that any processes that facilitate storage in LTS would be candidates for manipulation in learning situations if they could be identified and controlled. In research on consolidation these processes are difficult to separate from others, for example, those which might facilitate retrieval from storage, as Lewis pointed out. Consolidation may turn out to be fundamentally biochemical in nature, but even in that case there may be external events which would facilitate its occurrence.

The Formation of Associations

This is not an altogether satisfactory heading; since it usually implies a narrower view than will be taken here, and it might be objected by some theorists that the formation of associations occurs before consolidation. We are interested in processes which might facilitate the establishment of material in long-term store (LTS) and in the retrieval of this material when it is needed. On the input side, the opportunity for these processes to operate may begin in short-term store (STS), where, according to some stimulus sampling theorists, temporary associations are

formed (Estes, 1970) which may or may not become more permanent, depending on events and processes which follow. The very word "association" would displease other theorists, e.g., Asch (1969), who maintained that associating is really relating and that operations of relating are the basis of recognition and recall.

Although it may be that temporal contiguity is the necessary and sufficient condition for establishing temporary associations between two elementary events (Estes, 1970), subsequent relational operations on higher order units are possible, and it is possible that these operations facilitate storage in and retrieval from LTS. Asch (1969) maintained that to study the formation of associations is to study the coherence of experiences, using "coherence" for the fact that we refer given experiences to each other in a manner that unifies them. He suggested that what is most important about contiguity is that it is a condition for the emergence of relations. Asch discussed relations and relating in the following terms:

> "1. Relating and associating refer to wholly different concepts. To relate is to bring experiences into interdependence by means of mutual determination; the concept of association leaves no room for precisely this kind of interdependence. The sole formal content of the concept association is that of a 'connection' or 'path' that does not alter the terms connected. The only type of interdependence that associative accounts admit is therefore that of links in a chain; the terms connected are one thing, the connection between them another.
>
> These starting points have a number of divergent consequences that we will now sketch.

2. To refer to relations is to take seriously the contribution that the organism makes to the structuring of a situation. Relating is the organism's way of ordering, often dependent upon its indigenous capacities and often a necessary foundation for the operations of learning and memory. In contrast, the associationistic starting point presupposes an extreme initial lack of order, and aims to derive principles of ordering solely from the action of associations.

3. Given the operations of relating, it follows that the nature of the psychological stimulus is the first problem in the study of learning and memory. It is necessary to distinguish between the external and the psychological stimulus conditions. Activities of relating have their correlates in objective conditions, but they are not a copy of these conditions. The one-sided function of a contour in figure-ground articulation is not given in the objective conditions, nor is it derivable from them. Neither is the unity of a form composed of discrete marks part of the physical situation. The independent variables of this inquiry were phenomenally given kinds of interdependence. In this respect we have diverged from the S-R goal of treating learning and memory as a function of distal conditions alone. The latter strategy conceals problems, among them those here studied.

4. For the same reason, reference to relations brings one nearer to the conscious life of the organism. Relational structuring refers simultaneously to neurophysiological events and to their phenomenal correlates. Since the former are largely unknown, the latter are often an indispensable source of evidence and inference. The relations which served as the independent variables of the preceding investigation were strictly phenomenal facts.

5. Given their central place in mental life, relations bring the study of learning closer to issues of general psychology. Relations are facts not only about learning but equally about perceiving, imagining, and thinking. To bring a relation, say a perceptual one, into the study of learning is to establish its relevance in both domains. In the study of learning it is necessary to go beyond the facts of learning." (p. 97)

ERIC

Asch presented evidence that the process of recall from memory is dependent upon a prior process of recognition, and that when this failed in a paired-associates learning task, subjects "had to relearn a well-formed and retained association as if it were completely new" (p. 101).

Recently, theorists have turned to an examination of the role of internal processing operations in the formation of associations. The terms "rehearsal," "organization," "imagery," and "verbalization" are encountered frequently in the literature. The effects of operations denoted by these terms on storage into long-term store (LTS) are being investigated. It may be that these operations include learning facilitators effective for use on more complex subject matter and in less restrictive contexts than necessarily used in laboratory experimentation.

Bower (1970a) presented an analysis of the method of loci, which has been known since ancient Greek times. This method consists, essentially, of storing to-be-remembered items in different imaginary geographic locations, say in different rooms of a house. It apparently was originated by public speakers who, lacking inexpensive paper and writing implements, had to find some way of remembering their speeches. When they wanted to remember, they imagined they were walking through the various rooms in which they had stored the information, recalling what was stored in each room in turn. Bower concluded the important ingredients of the method of loci were "the formulation of imaginal associations between known cues and previously unknown, list items at input and use of similar cues for recall" (p. 502).

Norman (1968) discussed other mnemonic techniques, e.g., the key-word system, and concluded that material is not easily learned unless

it has some structure, which, if not already present, must be provided by the categorization performed by the subject or by the application of a formal system of mnemonic cues. He also, as did Atkinson and Wickens, suggested that the structure of organization used in LTS seems to be determined by the limitations of primary memory (STS). Norman considered that the power of mnemonic systems lies in the rules and techniques they provide for reducing long, unrelated strings of material into short, related lists.

Bugelski (1970) reviewed research on the role of imagery in paired associates learning. He reported evidence that suggests words always evoke mental images of "things." He concluded that this imagery actually mediates the association between two words, and that the reason subjects respond with another word to a stimulus word in a free association test is that they have been instructed to do so! He found in his experiments with paired-associates learning that the formulation of images requires more time, seven or eight seconds, than often is allowed in the typical paired-associates experiment.

These studies represent a strong trend in current research which is attempting to elucidate the nature of the processes behind the time-worn simplifications of classical associationism. The general picture that seems to be emerging is of a learner who operates on events in several ways which ultimately determine whether or not "associations" are formed. Stimulus events evidently are decoded in terms of attributes or dimensions. Shepard (1963) pointed out that the same events may be decoded in different ways on separate occasions within the overall dimensional structure. Abstract stimulus events, e.g., words, evidently do evoke

ERIC

mental images, which are, in some sense, the primitives in the processes of association (Bugelski, 1970). These images seem to be the "familiar coin" at least some learners use in their thought processes. Relational operations, Asch (1969) maintained, are important determinants of storage in LTS. What the learner learns may be relations among "things" as a consequence of trying to relate things to each other.

A general impression gained from viewing these studies is that certain internal processing operations mentioned in them are worthy of more detailed examination as possibilities for facilitating learning of serial tasks. Chief among these are rehearsal and recall, organization, imagery, and verbalization. Although one trial learning may occur, repeated trials are usually required before the learner is capable of performing satisfactorily. Repetition, like contiguity, is a basic condition which provides the opportunity for other processes to operate.

Rehearsal and Recall

Two of these processes under the control of the learner are rehearsal and self-initiated recall. We will distinguish between the two on the basis that rehearsal is concerned with keeping information which has come into STS from a sensory register from disappearing from STS for some short interval of time, whereas self-initiated recall is used to go back over information retrieved from LTS for any of several reasons. This distinction may not be necessary since some theorists might use the term "rehearsal" for both operations.

Rehearsal is discussed in the context of studies of STS (*e.g.*, Atkinson and Schiffrin, 1968; Atkinson and Wickens, 1970; Sternberg, 1969).

Sternberg (1969) used the choice-reaction time experiment to reveal (STS) memory scanning processes. His experiments led to the discovery that people use two kinds of processes in searching memory to retrieve information from short, memorized lists; a high-speed, exhaustive scanning process, used to determine the presence of an item in the list; and a slow, self-terminating scanning process used to locate an item in the list. He found no evidence that a person can "think about" more than one thing at a time. Evidently a list maintained in active memory must be scanned serially, item by item, and cannot be compared simultaneously to a test item. However, maintaining even a well-learned list in active memory makes it more readily available. He also found evidence for the assertion that visual rather than auditory memory-representations are used to compare to representations of visual stimuli. Furthermore, his experiments indicated that the same search process can be involved in both recall and recognition.

These experiments were based on the assumption that the time between stimulus and response is filled by a sequence of processes or stages which do not overlap. However, Sternberg made the assumption of selective influence on stages by a change in the task, rather than the assumption of "pure insertion" used in the early CRT experiments around the turn of the century. Sternberg found a linear relationship between mean reaction time and the size of the positive set of stimuli.

The intercept measured latency, indicative of the time required for stimulus-encoding, and the slope measured list-processing time, during the serial-comparison stage. In this context, rehearsal is used by the subject to maintain a list of items in STS for some necessary length of time. (In Atkinson and Wickens view, transfer to LTS occurs only while

ERIC

an item is in STS.) Rehearsal is, then, a form of covert repetition engaged in by the learner which may aid transfer to long-term store. When the material to be learned is broader in scope than the digits or syllables in paired-associates, rehearsal may be a matter of keeping the representation of some just-encountered material intact in STS while it can be examined by other processes, or simply to complete its meaning, as might occur in analysis-by-synthesis of difficult sentences. The learner may use rehearsal to assure himself that he can repeat a just received sequence. The deliberate use of rehearsal would seem to have value for reducing errors of communication caused by fragmentary or unfamiliar inputs.

Self-initiated recall might be regarded not only as practice in retrieval, but also as a covert trial that provides the opportunity to operate on the recalled material. Students can engage in learning operations at times other than those formally designated: everyone knows it is possible to "think about something" or to "run something through your mind" at any time selected, so long as the material can be recalled. No doubt a large proportion of this kind of mental activity is to be classified as day dreaming, but it also can be and is used to facilitate learning. "Thinking about something" can involve more than phantasy. Thinking about something that is to be learned typically occurs when the learning involves an unsolved problem or the learner has committed an error which resulted in some distress to himself. Under these conditions, he may engage in mental activities designed to solve the problem or to ascertain the cause of the error.

Under these conditions, some kind of imagery probably occupies the period of recall. Perhaps the learner "goes back over the session" in which the problem or error occurred, examining recalled circumstances leading up to the incident. Just what is "visualized" here is a mystery. Bower (1970a) maintained that "the information represented in the ordinary memory images is largely conceptual, generic, schematic -- hinted-at 'ghosts' of objects distributed about a schematic theater space" (p. 502). Imagery will be discussed below. The point here is that this kind of recall is a process which facilitates learning, and which provides the opportunity for other facilitating processes to operate.

These post-storage processes, are, we maintain, characteristic of intermediate and later stages in learning and are necessary for mastery of subject matter and performance. Although learning is inferred from performance, the two are different, as Tolman pointed out, and as many experiments on latent learning suggest. During self-initiated recall the learner may test his knowledge of how some thing works by tracing through its operation, he may attempt to visualize or verbalize to himself relationships among parts of a device, he may try to enummerate the number of items of a particular class in the device, he may try to predict when the device would fail under certain conditions, or he may imagine that he is operating the device and run through operating procedures or anticipate probable effects of certain operating conditions.

During self-initiated recall, the learner may try out the application of rules he is trying to learn by thinking of examples and attempting to apply them. He may try to formulate rules from experiences to improve his performance in future similar circumstances. He may test the limits of

rules to see where they do not apply. He may try to understand rules by thinking of analogies or by making simplifying assumptions, or by analyzing them into subsidiary rules.

No doubt there are many other similar processes that could be used by learners during self-initiated recall which would improve retention of material. Analogous processes probably are available for thinking about performance. The athlete goes over his performance before and after the game, analyzing movements and sequences of movements. The serial-task performer can review the structure of tasks he has performed to see where he went wrong or what parts he is not sure about or how he could improve.

We suggest these internal processing operations do facilitate retention, in part by establishing in the learner's mind what he knows and does not know, by transforming material to familiar terms, and by increasing his control over his performance. We hypothesize that the use of internal processing operations during self-initiated recall is by no means a universal habit; that, on the contrary, there probably are large individual differences in the ability to do this, and further, that this ability does distinguish between slow-learners and fast-learners. It seems to us that some features of educational technology do not encourage the development of these habits; too much information can be presented too rapidly, so that the student is reduced to the tactic of taking notes and parroting back bits of information, without learning to sustain long periods of self-initiated recall and to apply internal processing operations during these periods.

Organization

The effects of the organization imposed by the learner on the material to be learned extend from sensory and perceptual decoding to deliberate efforts to reorganize, to discern coherent patterns, to transform, and otherwise to impose a manageable structure on it to the organization of appropriate responses. In one sense, organisms are spatial and temporal pattern learners. There is some basis in the known organization of the nervous system for this assertion; Pribram (1969) has discussed functions of cerebral structures in these terms.

There can be no doubt that organization of content is a major problem both for the instructional technologist and for the student. Anyone who has attempted to do technical training will attest to the never-ending task of organizing content for presentation to the student. Researchers who attempt to do research in technical training usually find most of their resources must be devoted to content organization. Some of the operations the learner may deliberately perform to organize content for himself are mentioned in the subsequent sections concerned with imagery and verbalization.

Recently, theorists have become concerned with internal organizing operations nearer the sensory input end of the learning processes. An outstanding series of studies are those described by Bower and Winzenz (1969). They investigated the effects of grouping and coding on memory for digits. In the first two of eight experiments they found "devastating effects" of altering the phrase structure of digit strings on their recall. The hypothesis was that, if the learner learns a series of digits by imposing stable functional groupings on it, then his learning might be seriously retarded by forcing him to adopt different groupings each time the same

series reruns. "Repetition of a series with the same group structure would lead to improvements in its immediate recall, whereas repetition with a changing group structure would produce relatively little improvement in recall" (p. 2). This was confirmed in their first two experiments. They observed that the normal improvement in recall with repetition "was practically annihilated" by changing the group structure at each repetition. In all but one of these eight experiments, the experimenter imposed the group structure on the digits by saying the digit names with variations in rhythmic stress and pausing.

In the subsequent experiments, Bower and Winzenz investigated questions concerning a "reallocation" hypothesis and a "phoneme" chaining hypothesis. According to the reallocation hypothesis:

> "the perceptual coding of the input material determines a metaphorical 'location in memory' at which it is stored. If two serial sequences are coded in substantially similar ways, the second input is shunted to the same storage location, there to make contact with and strengthen the trace of the first input of this series. The hypothesis requires the further assumption that immediate recall of a series in this type of experiment is mediated by the strength of the trace in the most recently activated storage location. Thus, a series that is coded and stored in a consistent manner can accumulate trace strength to improve recall, whereas a newly coded (RC) item is shunted to a new location, and its recall from that location is similar to that of a once-presented noise item." (p. 6)

According to the phoneme view, the method used for imposing groupings:

> "in fact sets up a direct correspondence between a grouped series and a sequence of input phonemes. This view would then suppose that it is this

phoneme sequence which is rehearsed and stored as a chain of associations. When an old digit series is regrouped, it now produces a new phoneme string; this fails to "contact" the trace of the phoneme string used previously, and hence no repetition effect is observed in its recall. This phoneme view of matters is attractive because other evidence (cf. Adams, 1967) suggests that immediate memory is affected by phonemic variables." (p. 6)

Results supported both hypotheses up to a point, and generally confirmed that alteration of the group structure of a digit series degrades recognition of underlying identity, and prevents the improvement in recall that normally accompanies repetition.

Bower (1970b) reviewed his research on grouping and relating as basic cognitive processes; relational rules and perceptual-conceptual groupings, in the context of laboratory learning paradigms. He also discussed his investigations of the nature and influence of retrieval schemes including interchunk associations, pegword mnemonics, semantic category cuing, and hierarchically embedded category systems. These schemes provide implicit cues to guide the learner's search through memory. He concluded that:

> "By one or another means, the learning materials are segmented by the subject into integrated groups which become his functional recall units. Recall suffers if the subject is made to adopt new groupings of the same material. The results on digit series were interpreted by the 'reallocation' hypothesis, which ties together the perceptual coding of a string and the 'memory location' at which its trace is stored, with implications about recognition memory and trial-by-trial increments in recall of the same string. In free recall, the stable groupings of list words which develop are often supplemented by the subject developing a higher-order retrieval scheme to guide his reproduction of the many items on the list." (p. 18)

> "Hierarchical schemes, based on recursive associative decoding, are particularly effective retrieval plans.

The results are discussed in terms of the advantages of common strategies preferred by human learners, *viz*., the tendency to subdivide and group material, and to do this recursively, producing a hierarchical organization of the information to be learned." (p. 18)

In short, he found subjective coding of an event determines important features of its recall. What we remember, Bower said,

"is our cognitive autobiography, not stimulus and response events." (p. 41)

Bower commented on the possibility that the pervasive occurrence of hierarchical structures in nature is really a reflection of man's predisposition toward "projecting" such structures upon the world because the capabilities and limitations of his storage and retrieval mechanisms make it "natural" to do so. Perhaps, as Simon (1969) pointed out, for fast and efficient retrieval, given the limitations of conscious attention, linked hierarchical list structures would be one of the better ways to organize masses of information.

O'Connell (1970) reviewed studies of the facilitation of recall through the introduction of linguistic structure in nonsense strings. A nonsense string is a sequence of wordlike elements presented to subjects either orally or in written form. He noted that this research "has one foot in verbal learning and one in psycholinguistics" (p. 451) and thus has not received attention from either group. Although he concluded that facilitation of recall by linguistic structure in nonsense strings has been demonstrated, he observed that neither psycholinguists nor verbal learning theorists, nor this third group have up to now been able to cope with the fact that linguistic behavior occurs in particular contexts which are

critically important in determining the message. Quite different messages may be conveyed in different situations by identical linguistic tools.

Imagery

Holt (1964) reviewed the history of the topic of imagery in psychology, noting its early popularity, its sudden banishment as a consequence of the failure of introspection as a method and the rise of Watsonian behaviorism, and its return to semi-respectability, at least, in recent years, because of events which "forced it back into psychology's best parlors" (p. 263).

Paivio (1969) reviewed mental imagery in associative learning and memory, and presented evidence for its effectiveness in facilitating this learning (Paivio, 1969; Paivio, Yuille, and Rogers, 1969). He found that pictures of objects are more readily recalled than their labels, concrete words are superior to abstract words in paired-associate learning, recall, and recognition, and that the rated imagery value or concreteness of words is a better prediction of paired-associate learning than more traditional measures (Paivio, Yuille and Smythe, 1966).

Paivio, 1970; Rohwer, 1970; Reese, 1970; and Palermo, 1970; reviewed research on imagery in children's learning. Paivio described his conceptual-peg hypothesis:

> "that high imagery, or concrete, stimulus terms such as 'house' function as efficient stimulus 'pegs' from which associates can be hung and retrieved by means of mediating images." (pp. 387-388)

He described research (Paivio and Csapo, 1969) which found that visual imagery is efficient for storing item information in memory, but not for storing sequential information. They found the verbal symbolic system is more efficient for storing sequential information.

ERIC

Rohwer recommended that children should be taught to use both the verbal and visual kinds of elaborative activities as a way of increasing their own powers of learning. He suggested that information can best be presented to children in concrete and pictorial, rather than abstract and verbal form, and that items to be associated should be presented in some kind of meaningful context, or in some kind of spatial relation, or meaningful interaction. He pointed out, however, that the child cannot always count on the world to offer up information in optimal ways.

Bugelski (1970) also reviewed research on the role of imagery in learning, and presented results of his and his associates work with deaf children to test the relative contributions of verbalization and imagery in learning of nursery school children. He found that deaf children, who had no language, could learn to associate one picture with another. In other studies, he found that having subjects actually imagine a relationship between the members of a pair of words was significantly better than supplying mediators for them. He found that "imagers" were able to remember significantly more response words than "sentence formers." He concluded from the studies he reviewed that:

> "I am becoming increasingly convinced that all words are both abstract and concrete in that they are first symbols, to begin with, which makes them all abstract as divorced from things and events. They are all concrete in that they arouse a kind of activity in our neural mechanisms that was active at some prior time when we saw or heard something and words were also used at the same time. The revival of these former sensory-perceptual and emotional responses appears to be the meaning of the words that arouse them. These meanings can be shared or communicated among those with similar backgrounds but will, in all probability, never be identical." (pp. 1011-12)

ERIC

Shepard and Chipman (1970) proposed a "second-order" concept of isomorphism, observing that an internal representational event, e.g., a mental "image" of a square, need not have structural isomorphism with the external object. They maintained only that some degree of parallelism "should hold between the relations among different internal representations and the relations among their corresponding external objects" (p. 1). Using subjective similarities judgments and a type of multidimensional scaling procedure, they found positive evidence for their "second-order" isomorphism concept. Similarity judgments among the shapes of 15 U.S. states were found to be very much the same whether the stimuli were pictorially displayed or only imagined from their names, and further, these judgments in both cases were related to identifiable properties of the actual map shapes.

Their approach to the study of internal representations utilized "the fact of inadequately appreciated significance that despite the practically unlimited range and diversity of possible internal representations, we can readily assess within ourselves the degree of functional relation between any two by a simple, direct judgment of subjective similarity. Moreover, we can do this even though (a) we have never before compared the two representations in question, and even though (b) we may be unable to communicate anything about the absolute nature of either of the two representations taken separately" (p. 2).

In the analysis of a mnemonic device, Bower (1970a) presented the finding that college students instructed to associate two concrete items by "imagination imagery" could recall one and a half to three times better than those subjects who learned by whatever other means students typically use. He then discussed some of the properties of learning

ERIC

produced by such imagery instructions. Among these were the fact that subjects frequently substitute concrete words for abstract words they are trying to recall, suggesting they forgot the linguistic tag on a concrete image supposed to remind them of the abstract word; the fact that if the learner can be induced to form vivid, interesting images, intention to learn and motivation are of secondary importance; the reduction in differences in associative learning between normal and mentally retarded children when both are trained to proficient use of mental imagery; and the facilitation of associative learning among objects in an imaginable scene only if they are depicted in some kind of "interacting unity." This refers to Asch's (1969) coherence or interdependence of the various parts of a figure.

Bower pointed out that associating the main elements within pictures or images or sentences reveal similar properties, which suggests that a single factor may be responsible. One possibility is that imagery effects are due solely to verbalization -- that verbal encoding is the critical factor. Bower discussed counterevidence for this strict verbal hypothesis: people remember sensory information they cannot verbalize; concrete word pairs are learned much better than abstract word pairs; subjects who study "actor-action-object" sentences give better cued recall of the sentences if told to visualize the described scene at the time of hearing them; kindergarten children differ markedly in their recall of unitary scenes versus nonunitary scenes although their linguistic descriptions of the two scenes are quite similar; and studies which show selective interference between a type of distracting task and the type of mnemonic strategy the learner is using. In this last case (Brooks, 1968), the interaction between the modality of the remembered information and the

modality of reporting it was considered to result from interference or division of processing effort between two competing tasks. Thus, remembering and reporting in the visual modality compete for a limited processing capacity. If the activities of remembering and reporting are in two different modalities, there will be less interference, or conflict. Bower presented evidence from his laboratory and from a study of Atwood (1969) confirming these interfering effects.

Bower then discussed evidence for dual processing systems: the view that nonverbal imagery and verbal symbolic processes are the two major components of thinking. He proposed that the verbal and imagery systems are richly interconnected, but pointed out differences between them; the imagery system is more attuned to representing and operating on concrete information, the verbal system is more suited to processing abstract information; visual imagery has many of the properties of a spatially parallel system, while verbal processes are better suited for handling serial information. He maintained that pictures or objects are remembered better than their names because they establish two memory traces (image and verbal) rather than just one, and he reviewed neurological evidence from split-brain studies (Gazzaniga and Sperry, 1967) supporting the view that there are dual, imagery and verbal, processes. These investigators found evidence from testing split-brain patients that:

> "Both (cerebral) hemispheres can understand and react intelligently to language, but only the left can produce it in speech or writing." (p.509)

In contrast, the right hemisphere appeared somewhat better at non-verbal learning and spatial abilities. (see also Penfield, 1969)

Bower suggested that our general cultural de-emphasis and decline of mental imagery may well have resulted in neglect of a powerful learning facilitator, and recommended to the adult approaching a new learning task that he should:

> "become as a child again, to tap the wellsprings of his suppressed imaginative talents that have lain buried under years of linguistic development." (p. 510)

These investigators have opened a long-shut door with their research. The results are clear; learners who are induced to use imagery in the formation of associations remember better. Images plus verbal tags seem to be even more effective. Can imagery be harnessed for facilitating learning of serial tasks? There appear to be two alternative but not necessarily mutually exclusive approaches: the instructional technologist could provide the imagery or he could induce the learner to generate his own. The implication of the research that has been done is that the learner should learn to generate his own; looking at a picture and evoking one in memory involve different internal processing operations. However, there are many kinds of technical information which may leave the beginning learner at a loss for appropriate images. It could be feasible to provide some guidance initially; i.e., to teach the learner appropriate tactics for imaging, and then to arrange conditions so that he would be induced to continue developing imagery in the context of the scheme that was provided. Those who must learn to troubleshoot electronic equipment must learn something about how the equipment works, and must be able to use the knowledge to guide their search for a malfunction. With the exception of some output displays and special transducers, test equipment, which present visual or

or auditory evidence of what is going on, the technician must work in a symbolic world; electrons are not visible. Thus, "how something works" might be a category of learning that would be facilitated by this approach.

The structures of serial tasks are not at all evident to the learner. The temporal pattern is something he must learn. In some areas of knowledge this is recognized; e.g., in mathematics algorithms may be provided, and teaching the student to generate his own by making him work hundreds of problems are common instructional tactics. Many serial tasks encountered in the world of work are strings of several different kinds of subtasks requiring different skills. Learning might be facilitated by, e.g., a computer-driven display which presented a "map" of the task and its requirements which would become progressively smaller as the learner accomplished subtasks.

Indeed the computer-driven display can be used to facilitate learning with imagery. Perhaps an ideal application would provide the display and associated computer as a tool for the student to use for exploring the appropriateness of various forms of imagery for depicting how something works or how two things are related or how new material fits a context of old. The key requirement evidently is to get the student involved and to induce him to generate his own imagery.

Verbalization

The quite remarkable human ability to learn and speak languages provides humans with a powerful tool to use to facilitate learning. Although there is recent evidence that primates can learn simple language (Gardner, 1969), although they cannot make the sounds of human speech, and we may infer that primates in the jungle communicate what is important to them,

the capacity for verbalization does set human learning apart from animal learning. The learning experiment paradigms of the experimental psychologists were derived from animal conditioning paradigms, which may be one reason these theorists have had very little to say about the role of verbalization in learning. Yet most education and training are conducted with language. We can imagine the difficulties of accomplishing training without printed or verbal instructions or other descriptive material.

In the context of our interests in internal processing operations which may facilitate learning and retention, the usefulness of verbalization engaged in by the learner will be examined. It would appear that he can use verbalization in several ways to facilitate learning. He can give himself instructions, encouragement, admonitions, etc., in short, monitor his own behavior somewhat as though his "self" was a separate person. At least some, possibly most people "talk to themselves" in this way. Language probably helps them define a self-concept and conceive of it as a controllable entity, which they can commit to the task of learning, and supervise, correct, praise, and evaluate during learning.

Language can be used to "think about learning," to formulate tactics, to describe steps in a learning task, to survey the extent and possible requirements of a learning task. It can be used to formulate opinions and attitudes about conditions of learning and material to be presented, the methods of presentation, and the instructors involved.

Verbalization can be used to facilitate "the formation of associations" in terms of our broad definition. It can be used in relational operations of comparing, drawing analogies, or classifying. It can be used to guide covert tryouts of performance; i.e., to talk oneself through a serial-

task, or simply to "put something in my own words." It can be used to help establish a mental organization of material, to guide the search for patterns, to fragment material into smaller chunks, to reduce it to simpler terms, to dramatize it, to give a self-test. Probably the reader can think of dozens of other possibilities. The extent to which learners do use verbalization for these purposes is not known, nor is the effectiveness of these tactics. We hypothesize that they could be extremely important in helping the learner to learn, if specific tactics for using verbalization were taught to him.

Montague and Kiess (1968), as part of a series of studies on the effects of subject-generated associative devices, specifically, natural language mediators, (Montague, Adams, & Kiess, 1966; Montague and Wearing 1967a, 1967b) described a measure of associability value, the AS. This measure was based on the proportion of subjects able to generate a natural language mediator (NLM) which linked the stimulus and response in CVC pairs. Montague and associates have found that NLMs facilitate acquisition of paired associates.

McGuigan (1970) has summarized and evaluated research in which covert oral responses were recorded during the silent performance of thinking tasks. He concluded that:

> "1. Covert oral behavior significantly increases over base line, 2. the increased covert oral behavior is accompanied by increased respiration rate and increased amplitude of electromyograms in the preferred (writing) arm, but appears to be relatively independent of other nonoral behavior; and 3. covert oral behavior does not appear to typically increase during the performance of non-langugage tasks. A set of five directly relevant findings leads to the conclusion that covert oral behavior during the silent performance of language tasks serves a language function; mediational theories, built on overt behavior, help to suggest

> more precisely that the covert oral response facilitates the reception of external language stimuli and the internal processing of that information. Physiological considerations indicate complex and rapid feedback loops between speech regions of the brain and the speech musculature. These loops may function in the process of internal communication." (p. 309)

The Role of Dual Processing Systems in Observational Learning

Nonverbal imagery and verbal symbolic processes are an important basis of observational learning. Bandura (1969) described research on modeling and vicarious processes in which their role was investigated. Observational learning refers to the fact that one of the fundamental ways organisms learn is to watch other organisms perform. Ethologists have documented the occurrence of observational learning among animals (*e.g.*, Washburn and Devore, 1961).

Bandura pointed out that:

> "Research and theoretical interpretations of learning processes have focused almost exclusively on a single mode of response acquisition which is exemplified by the operant or instrumental conditioning paradigm. In this procedure an organism is instigated, in one way or another to perform responses, and approximations progressively closer to the desired final behavior are selectively reinforced. It is generally assumed that complex human behavior is likewise developed under naturalistic conditions through this type of gradual shaping process.
>
> Fortunately, for reasons of survival and efficiency, most social learning does not proceed in the manner described above. In laboratory investigations of learning processes experimenters usually arrange comparatively benign environments in which errors will not produce fatal consequences for the organism. In contrast, natural settings are loaded with potentially lethal consequences that unmercifully befall anyone who makes hazardous errors.

> For this reason, it would be exceedingly injudicious to rely primarily upon trial-and-error and successive approximation methods in teaching children to swim, adolescents to drive automobiles, or adults to master complex occupational and social tasks. If rodents, pigeons, or primates toiling in contrived situations could likewise get electrocuted, dismembered, or bruised for errors that inevitably occur during early phases of learning, few of these venturesome subjects would ever survive the shaping process." (p. 143)

Bandura reviewed animal studies which showed that primates and dogs are capable of observational learning. In a study by Warden and his associates (Warden, Fjeld and Koch, 1940; Warden and Jackson, 1935) naive rhesus monkeys achieved instantaneous imitative solutions of four problem solving tasks in 76 per cent of the test trials, while watching trained monkeys solve the same problems. Adler (1968) found puppies could solve problems through observational learning soon after their eyes became functional. Bandura pointed out that it would be difficult to imagine a culture in which "language, mores, vocational and avocational patterns, familial customs, and educational, social and political practices" (p. 145), were learned without the response guidance of models who exemplify these cultural repertoires in their own behavior.

Bandura discussed four component functions that markedly influence the nature and degree of observational learning; attentional processes, retention processes, motor reproduction processes, and incentive and motivational processes. He called attention to studies in which rehearsal operations were used to stablilize and strengthen acquired responses. Of particular interest here is evidence found by Michael and Maccoby (1961) that covert rehearsal, which can be engaged in when overt participation is impractical, can enhance retention of acquired matching

ERIC

responses (matching the model). Bandura pointed out that people rely extensively on verbal modeling cues for guiding their behavior; they can assemble mechanical equipment, acquire rudimentary social and vocational skills, and learn appropriate ways of behaving in "almost any situation" by "matching the responses described in instructional manuals" (p. 146). He distinguished between instigational and modeling functions of instructions; they are most likely to result in the correct performance when they "both activate a person to respond and describe the appropriate responses and the order in which they should be performed" (p. 146).

The imagery and verbal processing systems, then, can be utilized in conjunction with observational learning situations in which a model demonstrates the behavior to be learned and the learner verbally decodes stimulus events, or he is provided with ready made images or instructions, which he can operate upon with these processing systems. Various arrangements of conditions to insure that the learner does use these systems are possible. Of great importance, of course, are conditions which induce the learner to attend to the model's behavior and discriminate the important cues. The use of audio-visuals, for example, short movies depicting how to do something, is an old training method, but effectiveness depends upon these conditions. Bandura cited studies of social learning that found that models who have demonstrated high competence, who are purported experts, or celebrities, and who possess status-conferring symbols are likely to command more attention. He pointed out there "would be little incentive to prepare oneself for, or to practice covertly, the behavior of models who command no rewarding or punishing power" (p. 140).

ERIC

More to the point here, Bandura maintained that imaginal and verbal processing systems are used to code modeling stimuli into images or words for memory representations that are used for subsequent response retrieval and reproduction. A person observing a model's behavior but not performing every response himself can acquire the modeled responses only in "cognitive, representational forms" (p. 133). Although the learner does not engage in any overt responding trials, he may require multiple observational trials before he can reproduce the modeled stimuli accurately.

Bandura assumed imagery formation under these circumstances occurs through a process of sensory conditioning. He cited studies (Conant, 1964; Ellson, 1941; Leuba, 1940) which indicated that:

> "In the course of observation, transitory perceptual phenomena produce relatively enduring, retrievable images of modeled sequences of behavior. Later reinstatement of imaginal mediators serves as a guide for reproduction of matching responses." (p. 133)

He believed that the verbal representational system probably accounts for the "notable speed of observational learning and long-term retention of modeled content by humans" (p. 133), and that most of the cognitive processes that regulate behavior are primarily verbal, and pointed out that once modeled sequences of responses have been transformed into readily utilizable verbal symbols these can be utilized to covertly control later performances of matching behavior. He cited two studies (Bandura, Grusec, and Menlove, 1966; Gerst, 1969) which found that verbal labelling of modeled responses in a film was superior to watching attentively or to coding modeled items in vivid imagery, for retention of matching responses.

SECTION V. TRANSFER TO TRAINING

The general picture that emerges from the research reviewed above is of a learner with limited channel capacity for attending to sensory inputs and for performing actions on the environment. Internal processes, operating over a period of time and utilizing the central results of many stimulus-response cycles, gradually build up a model of significant features of the environment and a collection of serial response patterns, both presumably hierarchically organized. These enable the learner to gain more control over himself and his relationships with the environment by organizing appropriate internal representational and processing operations into behavioral generators. These guide the more effective employment of the limited stimulus-response apparatus in coping with the perceived demands of a situation. During learning, the stimulus-response cycle provides sensory information and response-feedback information for the internal processing operations to operate upon. These operations are primary among the determinants of the rate and nature of learning.

The current picture of internal processing operations on the input side of the organism is more detailed than is the case for operations on the output side. However, there is some basis for inferring that the output side is highly organized in terms of "wired-in" body-orienting, postural, locomotor, and manipulatory reflexes which operate with no or a minimum load on conscious awareness. Learned serial response patterns may be superimposed on, and involve temporary configurations of, these wired-in reflexes.

ERIC

A number of theorists have observed that well-learned habits do not require continual attention for their performance. Once performance is started, then attention need only occasionally sample progress. Otherwise, attention can be directed elsewhere. This learning process of freeing attention from continually monitoring action-by-action on-going activities would appear to be fully as deserving of research as are consolidative processes. Is some program laid down in long-term memory that can be run-off without occupying space in short-term store? Does local afferent feedback provide the guidance that unburdens attention? Do well-learned habits come more under the control of neural mechanisms that guide "wired-in" reflexes? Do organizational strategies enable attention to deal only with superordinate category labels?

Learning and retention, in this picture, are facilitated by selective, organizational, representational, relational, and rehearsal processes the learner uses on the material to be learned. Outstanding among these are imagery, verbalization and organization.

The key to improving learning and retention, the theorists are saying, is to induce the student to take the initiative in operating on the material to be learned. *His* organizing operations, *his* imaging operations, *his* verbalizing operations construct the models of selected features of the environment and develop the intellectual skills which *he* can use to guide his performance. The active learner, actively trying to perform criterion tasks can repeatedly test the adequacy of his models and his skills through feedback. He modifies them in relation to the outcomes of these self-tests, until he achieves confidence that he can rely on them. If the material to be learned is too difficult; *i.e.*, if his prior learning is inadequate

for this learning task or if the material is presented too rapidly, he may not develop models and skills in which he is confident.

We should not expect to find in the experimental literature ready-made prescriptions for improving learning and retention in the classroom. It is likely the experimentalists' view of this would be that not enough is known about fundamental processes as yet. As Estes (1970) put it, after surveying the literature of learning theory in relation to mental development:

> "The general impression created by this review of empirical and theoretical literature is that a discipline having to do with the development of learning ability has only begun to take form. Some of the essential ingredients are beginning to appear, but major efforts up to the present have been concentrated upon a few facets of a problem which needs broad-scale and sustained attack." (p. 183)

He proposed that there are two main tasks for advancing a science of learning ability:

> "1. The first of these, logically at least, involves the identification of elementary capacities and the tracing of the course of their maturation in the developing organism. Quite possibly, major theoretical progress on this line will have to wait upon the advance of behavioral and neurophysiological analyses of simple forms of learning and related behavior-genetic analysis." (p. 184)

> "2. The second main task is identifying learning processes whose products are important determiners of subsequent learning, investigating the conditions of initiation and maintenance of these processes, and tracing out the mode of their organization at various stages of development." (p. 184)

Estes concluded that "the contacts between learning theory and the empirical study of mental development have been sparse and unsystematic" (p. 187).

ERIC

He discussed reasons for the relative isolation of the two disciplines, among them the theoretical one-sidedness of laboratory research on learning in this country, which concentrated on:

> "... relatively simple forms of conditioning and learning, where similarities over age levels are more conspicuous than differences. It is well known that diagnosing a weakness in scientific strategies rarely leads in any direct way to reform, but even so there are some grounds for guarded optimism in the present instance. At least a partial remedy may already be taking form in the increasing emphasis on more complex phenomena of learning and memory, with the attendant increasing need to deal with the organization of learning and cognitive processes." (p. 188)

At the conclusion of his review of association and organization, Mandler (1968) commented, in similar vein that:

> "We are only at the beginning of a rather imposing task. We must specify the nature of mental organization, the rules for storage and retrieval, and the initiation and operation of transformation rules. The literature on associative behavior is the beginning; it tells us what must be explained. And we have a lot of explaining to do." (p. 119)

Two directions to go from here are apparent: research on "learning to learn" in the context of meaningful material, and reorientation of the goals and methods of instructional technology to give learning processes proper emphasis in relation to learning products.

Research on Learning to Learn

This is not to say that no research on this has been done; "learning to learn" is discussed by McGeoch, 1942; Harlow, 1949; Duncan, 1960; and

Postman, 1969. Harlow discribed his classical research with learning-sets in primates. Duncan (1960) observed that although learning to learn is supposed to be a commonplace, there is practically no literature in the area of human learning. Duncan reported a study of learning to learn in the context of a paired-associates task. He concluded that learning to learn greatly improved rate of learning, especially on early trials. He found that slow-learning subjects "benefitted enormously" from learning to learn. He concluded that:

> "... the improvement in performance produced by learning to learn is so great that to measure it adequately, the tasks used should have practically no limit on possible achievement." (p. 114)

Harlow's and Duncan's research tells us that drill and practice in performing a series of similar tasks results in learning to learn. A similar effect is observable in the results of CAI research reported by Atkinson (1968) and Suppes and Morningstar (1969). Drill and practice provides the opportunities for the student to use learning facilitators.

But, can conditions be arranged within these opportunities to induce the learner to learn more effective learning strategies than he is accustomed to using? And can these strategies and their effects be identified? The research discussed in the preceding pages suggests that this is worthy of consideration. The internal processes which might be the targets of such research would be found in selective attention; consolidation; rehearsal and self-initiated recall; the dual processing system, imagery and verbalization; content organization, and response organization.

Postman (1969) addressed the possibility that learning strategies can be brought under experimental control by manipulating the conditions of

practice. He maintained that "there is no fundamental discontinuity between the principles of specific and non-specific transfer" (p. 242). The hierarchy of habits and skills may vary in their applicability to particular situations, but they must be presumed to be equally specifiable and to be governed by the same laws. Postman described a series of experiments focused on "the identification of the component skills that are responsible for the increases in the proficiency with which successive (verbal) learning tasks are performed" (p. 256). Postman's experimental findings generally encouraged the view that learning to learn, in the context in which it was studied, can be brought under experimental control.

In the case of research on serial-task learning, a prior consideration is the development of more powerful procedures for controlling serial-task learning situations. If indeed learning results in a hierarchical structure of internal processing operations, most of the research on verbal learning reviewed above has been done at a level of complexity near the bottom of the hierarchy, whereas many serial tasks call for the intervention of internal processing operations that range from near the bottom to the top of the hierarchy. Serial behavior of this complexity is foreign to the experimentalist's laboratory.

Generating serial-task behavior of the type required in the world of work demands that additional internal processing operations be used. The conception of a serial-task generator includes operations for dealing with the temporal sequence of events. Experimental paradigms used in verbal learning were designed to permit manipulation of relatively few variables so that their effects could be observed in a highly simplified stimulus-response cycle in simple situations. They serve this purpose

well, but this purpose is to study fundamental processes in learning, not to teach students how to do something. Indeed, the classical paradigms were designed to prevent the adult human learner from using those learning facilitators he might possess and might be accustomed to using in daily life. It is no accident that, as Estes describes it:

> "Under experimental conditions which minimize the role of voluntarily controlled behavior, the acquisition of conditioned responses proceeds at very similar rates in animals, human children, and human adults. Similarly the rate of paired-associate acquisition for simple, nonverbal stimuli and responses varies little with age over most of the life span and differs little between mentally retarded and normal groups. And, retention of simple associations once established, if not actually independent of age and other indices of mental development, at least exhibits no systematic variation that has been detectable by research to date." (p. 32)

If he is to learn to perform serial-tasks, the learner must acquire information, concepts, and rules he can use to guide his performance, the ability to perform the different subtasks in the serial-task, and the ability to assemble selected internal processing operations into a serial-task generator appropriate for generating effective performance. A procedure for facilitating this learning must be capable of representing the tasks to be accomplished, of presenting these to the student, of tracking and recording his performance, and of allowing him to work at different levels in the hierarchy of internal processing operations, on the different kinds of subtasks which compose the serial-task. To be efficient, the procedure should allow the student to "find his own level;" that is, his prior learning will have provided him with a pattern of knowledge and skill that will let him start at certain points above the

fully instructed baseline and will require that he concentrate most on certain subtasks in the learning situation.

A mechanism for creating and controlling serial-task learning situations should be capable, then, of inducing the learner to learn additional intellectual skills and to learn to organize and manage sequential behavior. This mechanism might then be used in the research tasks proposed by Estes for advancing a science of learning ability. Many positive conditions will have to exist before, if ever, the sustained, programmatic research that is necessary can be done. However, the most likely basis for the necessary mechanism seems to inhere in the time-sharing data-processing technology.

A characterization of the requirements for serial-task performance may illuminate the order of complexity of this behavior, and therefore suggest specifications for a "learning environment controller."

1. The stimulus-response cycle occurs in a context of on-going behavior: stimuli, responses, and internal processing operations relating stimuli to responses vary across stimulus response cycles.

2. The serial-task performer must select and organize stimuli[1], internal processing operations, and responses in relation to superordinate stimuli called goals.

2a. The performance of serial-tasks requires time-sharing of attention among concurrent requirements.

2b. The performance of serial-tasks requires that the performer be able to empty as well as fill short-term store in response to changing characteristics of the task.

2c. The performance of serial-tasks requires that the performer monitor his own performance.

2d. The performance of serial-tasks requires that the performer be able to program, or instruct himself.

3. The information processed during serial-task performance in the world of work is related to an organized body of knowledge.

3a. Relationships between knowledge and performance are imperfectly mapped: a primary learning task for the performer is to learn to sample and organize from a body of knowledge the information that he needs to guide his performance.

3b. Assisting the learner in mapping the relationships between knowledge and performance is a primary task for training.

Despite the encouraging turn that basic research in learning and memory has taken, as illustrated in the above review, our current knowledge of internal processing operations is quite sketchy. In developing a learning environment, the better approach would appear to be to provide the opportunities for the adult learner to operate on the material to be learned, on the assumption he has strong self-organizing tendencies and can be led to apply these in the learning environment, while also providing for the use of known learning facilitators. This environment, then, could support research on different kinds of learning induction mechanisms. Although several "instructional strategies" are discussed in the literature of CAI, these seem not to have been designed with research on learning facilitators in mind. It is likely that specific mechanisms which can be "plugged into" the "learning environment controller" will have to be designed.

Meanwhile, some preliminary work on a "learning environment controller" for serial-task learning has been accomplished (Rigney and Towne, 1969). This work is based on several premises:

1. At the present stage of development of the data processing and instructional technologies, it is uneconomical and inappropriate to attempt to accomplish all instruction on-line with a time-sharing system. Some kinds of material can be learned more economically through the mediation of other methods.

2. An appropriate mixture of methods might utilize on-line instruction for drill and practice in performing criterion tasks. During these sessions the student would have the opportunity to experience the diverse elements of these tasks, and to discover his levels of abilities needed to cope with them. He might, then, utilize other materials and other forms of instruction to acquire information he found he needs, to observe a model performance of some subtask, or to resolve questions in his mind which were generated during the on-line practice.

3. The management of instruction, in terms of what the adult student should do next, should rely primarily on the student's ability to diagnose his own needs, using the computer program and on-line sessions as diagnostic tools, in addition to their drill and practice functions. The computer program could incorporate self-tests which the student could take, it could "replay" an entire practice session, step-by-step, commenting on the accuracy of performance at each step, it could allow the student to practice different kinds of subtasks, and it could provide a number of on-demand support functions which the student could call upon for help. Although the self-tests might be expected to carry the primary burden of helping the student diagnose his needs, these other features should also contribute to his knowledge of how well he can do. If he finds for example, that he does not know how to establish the appropriate operational configuration

of a device for sampling a desired kind of information about its state, as a consequence of taking a drill in making front-panel tests, he then has useful information about his abilities. If he finds that he cannot get through a troubleshooting problem without calling for help from the program, this also is useful self-diagnostic information.

4. Giving the student a large measure of control over scheduling his learning experiences and over the rate at which he proceeds will induce him to utilize more of his self-organizing capabilities and internal learning facilitators. This will result in improved learning rates and better retention.

5. A computer program designed as a learning tool for the student to use and to control will tend to induce the student to take the initiative in utilizing the tool for facilitating his own learning.

The serial-task domain selected for application of the learning environment controller was the operation and maintenance of devices. The boundaries of this domain are limited only by practical considerations of analysis of relationships among elements of the device and preparation of the data base. Generally speaking, this domain includes a set of serial tasks and a device whose states can be changed by operation of controls, and whose states can be inferred by sampling state information from indicators. The simulation of this performance environment with a computer program requires that essential features both of the device and of the serial task be simulated.

There undoubtedly are many different ways to meet these requirements in the logic and structure of a computer program. One way is to make the program general and the data-base specific. General logic for generating the types of student-computer interactions considered desirable was

incorporated in the program. Specific "outside world" labels to relate task-structures and devices to specific contexts and the relationships necessary to simulate essential features of a specific device were assigned to the data-base. Thus the program, TASKTEACH, is general: it is made specific to a particular context by the data-base. Additional details covering TASKTEACH I are available in the above reference. TASKTEACH II will be described in a forthcoming report. The point being made here is that the data-processing technology contains powerful tools for creating and controlling the complex environments considered to be necessary for research on learning facilitators in this context.

Reorientation of the Goals and Methods of Instructional Technology

Theorists have suggested that too much emphasis currently is given in training and education to learning "facts" and too little emphasis is given to the learning of learning and performance facilitators. Gagne (1970) maintained that intellectual skills are what should be taught, since they are what are remembered. Bower (1970b) suggested that we remember our "cognitive autobiographies," not "stimulus and response events." Estes (1970) concluded that rates of learning in most situations depend "to a major extent upon habits or strategies of selective attending, seeking of information, coding and encoding of stimulus information, rehearsing, and the like, and the manner in which these are organized" (p. 31).

The instructional technologist should, then, consider methods for inducing students to learn and to use these facilitators. He has at his disposal instructions, external organization of the material to be learned, scheduling of the learning episodes, and operations for providing feed-

back information and for providing reinforcement. The general shift in relation to his current objectives must be toward process rather than product. He must attempt to manipulate these external conditions to influence the student's internal processing operations in desired ways. He may attempt to do this using specialized episodes not necessarily related to any particular set of tasks or subject matter, or he may attempt to integrate his conditions into the context of a particular technical training environment. Both approaches are desirable, although the former is likely to be more feasible for programmatic research, while the latter is indicated for application of research results, and for search for the "big effect" in training. Among the possibilities he has at his disposal, those classified under the heading of reinforcement are currently a major preoccupation of theorists (Glaser, 1970). Conceivably, for example, ways could be found to reinforce selectively the acquisition and use of internal processing operations. Atkinson and Wickens (1970) viewed learning as:

> "The transfer of information generated by sources both external and internal to the organism into some form of memory store that can hold it until it is needed later. Reinforcement is a modulation of this information flow. A reinforcing event, in this sense, serves two functions: first, to set in motion the processes that cause the transfer to take place, and second, to select what information is transferred." (p. 100)

They described a number of experiments involving the manipulation of reinforcement variables, which demonstrated that the subjects' actual responses "frequently fail to provide an adequate indicator of the reinforcing processes involved," and "how superficially similar reinforcements can have markedly different effects, depending on the strategy used by the subject." (pp. 103-104)

The instructional technologist might, for example, concern himself with arranging external conditions to cause the use of appropriate learning facilitators to be reinforced over a period of time. Possibly this would be most effective if begun with young children, on the presumption that there may be a critical period for establishing these learning habits, and that known reinforcers are most effective with children. Since the topic of reinforcement has already been so intensively explored in many current references, further discussion in this review would be redundant.

We remarked earlier on the extraordinary amount of labor required to organize course material so that the student can progress from A to B to C. In technical and professional areas, the experts have erected barriers of technical jargon and special symbologies that separate them from the world at large. Is it convenient, and also status-preserving, for them to communicate in these obscure terms. They can write textbooks to impress each other, and they can produce technical manuals which only they understand. Thus much of the everyday, nitty-gritty work of the training specialist is occupied with translating this gibberish and "stretching it out" into a progressively graded sequence his students hopefully can follow. These translating and reorganizing operations result in a structure for the material which should serve as the basis for the students' own organizing and structuring operations. There is, of course, a considerable body of literature on how to do this external structuring, including detailed prescriptions for writing "training objectives," and producing lesson plans keyed to them. Our purpose here is to suggest in passing that more concern with relating this external organization to the characteristics of the dual-processing system, imagery and verbalization, may lead to organizations which are more suitable starting places for internalizing operations, and

to suggest that more concern might be given to mapping the relationships between knowledge and performance. The ultimate goal of technical training is to produce effective performers. Is it possible that this external organization of information could be more sensitive to these ultimate goals?

The dual-processing systems which Bower and Bandura discussed are, like all internal processing operations, very poorly known. As imagers and verbalizers, we each have developed private strategies for using these processes, but scientific knowledge about the best strategies for using these processes is scant. Nevertheless, the course organizer might consider when, indeed, a picture is worth ten thousand words, when a dynamic display is worth ten thousand pictures, and when, on the other hand, words are more effective than either. For example, we have for many years suggested that "visual electronics" might facilitate understanding basic circuits by beginning students. Adams (1970) has taken a step in this direction in his Electronic Circuit Action Series, illustrating electron currents in basic circuits, under static and dynamic conditions, with colored pathways superimposed on the circuit diagrams.

The economy and clarity of communication by these diagrams, of the fact that there are several currents and that they flow in different directions and in different parts of the circuit, are striking. However, the amount of text required and the awkwardness of the verbal explanation needed to explain the temporal sequence of events when these circuits are operating is just as striking. How much more compellingly a dynamic display could convey this information! Finally, consider a dynamic display under the student's control. The student could inject a signal, change values of components, or cause various components to fail, to explore these effects on the circuit's operation. The student would be induced to use his dual-processing systems

to build up his own images from these compelling external images, and to verbalize to himself observed relationships. We predict one hour of this kind of learning experience would be worth many hours of chasing imaginary electrons through printed schematics and using abstract mathematical equations for laboriously computing single data-points.

Bandura's discussion of observational learning, reviewed above, might also be taken seriously by the course organizer. Observational learning is nothing new; as Bandura pointed out, it is a fundamental way animals and humans learn to survive in an unforgiving world. But Bandura also pointed out that the student observer must engage in learning operations; thousands of ineffective closed-circuit television "lessons" demonstrate that. There are some things, serial tasks among them, that are candidates for observational learning.

The use of instructions for inducing students to learn and to use learning facilitators could include descriptions of the strategies to be learned, the goals of the learning, and the ways to proceed. Instructions obviously are an indispensable part of learning environments for humans. Communication between experimenter and subject, instructor and student, is indispensable. Where instructions are omitted or incomplete, the learner will, in fact instruct himself on the basis of his best judgment about what he should do. Although we have been taught to be wary of the power of instructions to alter behavior, they were used and were effective in many of the studies of internal processing operations reviewed above. Instructing students to "turn on their imagers" might turn out to be effective if combined with other conditions which would predispose them to use imagery. Bower used instructions to his subjects to get them to use particular organizational strategies, with demonstrated effectiveness.

Our views on scheduling learning episodes were set forth above for serial-task learning, in the description of a "learning environment controller." The essential strategy is to give the learner opportunities to try to perform interspersed with periods in which he can acquire information or practice skills he has found he needs to enable him to perform. This is a type of spaced-practice paradigm in which the intervening intervals are used to prepare for the next trial.

Throughout this review we have offered comments suggesting how the learning facilitators investigated by theorists in the experimental laboratory might be extended to and incorporated in the instructional environment. Our objective was to point to a door that has been opened a little way. What lies beyond remains to be discovered by the creative thinking and hard work necessary to design and implement methods for teaching students how to learn in the diverse subject matter contexts characteristic of that environment.

REFERENCES

Adams, J. A. Response feedback and learning. Psychol. Bull., 1968, 70(6), 486-504.

Adams, T. M. Electronic Circuit Action Series. Indianapolis, Indiana: Howard W. Sams & Co., Inc., 1970.

Adler, L. L. and Adler, H. E. Age as a factor in observational learning in puppies. American Dachshund, 1968, March 13-14.

Anokhin, P. K. A new conception of the physiological architecture of conditioned reflex. In J. F. Delafreshaye (Ed.), Brain Mechanisms and Learning. Springfield, Ill.: Charles C. Thomas, 1961.

Asch, S. E. A reformulation of the problem of associations. American Psychologist, 1969, 24, 92-102.

Atkinson, R. C. Computerized instruction and the learning process. American Psychologist, 1968, 23(4), 225-239.

Atkinson, R. C. and Shiffrin, R. M. Human memory: A proposed system and its control processes. In Spence, K. W. and Spence, Janet T (Ed.), The Psychology of Learning and Motivation, 1968, 2, 90-191, New York: Academic Press.

Atkinson, R. C. and Wickens, T. D. Human memory and the concept of reinforcement. In Glaser, R., The Nature of Reinforcement: Part I, Learning Research and Development Center, University of Pittsburgh, Pittsburgh, Pennsylvania 15213, June 1970.

Atwood, G. E. Experimental Studies of Mnemonic Visualization. Unpublished Ph.D. dissertation, University of Oregon, Eugene, Oregon, 1969.

Bandura, A. Principles of Behavior Modification. New York: Holt, Rinehart and Winston, Inc., 1969.

Bandura, A., Grusec, J. E. and Menlove, F. L. Observational learning as a function of symbolization and incentive set. Child Development, 1966, 37, 499-506.

Berlyne, D. E. Conflict, Arousal and Curiosity. New York: McGraw Hill, 1960.

Bond, N. A. Jr. and Rigney, J. W. Motivating The Student in CAI Technical Courses. Los Angeles: Univer. Southern California, Behavioral Technology Laboratories, March, 1971. (Tech. Rep. 68)

Bower, G. H. Analysis of a mnemonic device. American Scientist, 1970a, 58, 496-510.

Bowerer, G. H. Organizational factors in memory. Cognitive Psychology, 1970b, 1(1), 18-46.

Bower, G. H. and Spence, Janet, T. The Psychology of Learning and Motivation. New York: Academic Press, 1969, 3.

Bower, G. H. and Winzenz, D. Group structure, coding, and memory for digit series. J. exp. Psychol. Monographs, 1969, 80(2), Part 2, 1-17.

Broadbent, D. E. Speaking and listening simultaneously. J. exp. Psychol., 1952, 43, 267-273.

Brooks, L. R. Spatial and verbal components of the act of recall. Can. J. Psychol ., 1968, 22, 349-368.

Bugelski, B. R. Words and things and images. American Psychologist, 1970, 1002-12.

Cherry, E. C. Some experiments on the recognition of speech, with one and with two ears. J. acoust. Soc. Amer., 1953, 24, 975-979.

Chomsky, N. Current issues in linguistic theory. In J. A. Fodor and J. J. Katz (Ed.), The Structure of Language: Readings in the Philosophy of Language, 1964, Englewood Cliffs, N.J.: Prentice Hall

Conant, M. B. Conditioned Visual Hallucinations. Unpublished manuscript, Stanford University, 1964.

Deutsch, J. A. and Deutsch, D. Physiological Psychology, 1966. Homewood, Illinois: The Dorsey Press.

Dixon, T. and Horton D. (Ed), Verbal Behavior and General Behavior Theory. Englewood Cliffs, N.J.: Prentice-Hall, 1968.

Duncan, C. P. Descriptions of learning to learn in human subjects. American J. of Psych., 1960, 73, 108-114.

Elliott, H. C. Textbook of Neuroanatomy. Philadelphia: J. B. Lippincott Company, 1969.

Ellson, D. G. Hallucinations produced by sensory conditioning. J. exp. Psychol., 1941, 28, 1-20.

Estes, W. K. Learning Theory and Mental Development. New York: Academic Press, 1970.

Gagne, R. M. Learning and Individual Differences. Ohio: Charles E. Merrill Publishing Co., 1967.

Gagne, R. M. Contributions of learning to human development. Psychol. Rev., 1968, 75, 177-191.

Gagne, R. M. The Conditions of Learning. New York: Holt, Rinehart, and Winston, Inc., 1970, 2nd Edition.

Gardner, R. A. and Gardner, B. T. Teaching sign language to a chimpanzee, Science, 1969, 165(3894), 664-672.

Gazzaniga, M. A. and Sperry, R. W. Language after section of the cerebral commissures. Brain, 1967, 90, 131-48.

Gerst, M. S. Symbolic Coding Operations in Observational Learning. Unpublished doctoral dissertation, Stanford University, 1969.

Glaser, R. Learning. Learning Research and Development Center, University of Pittsburgh, Pittsburgh, Pennsylvania, Technical Report, Preprint 29, August, 1968.

Glaser, R. The Nature of Reinforcement: Part I. Learning Research and Development Center, University of Pittsburgh, Pittsburgh, Pennsylvania, Technical Rep., June 1970.

Greenwald, A. G. Sensory feedback mechanisms in performance control: With special reference to the ideo-motor mechanism. Psychol. Rev., 1970, 77, No. 2., 73-99.

Groves, P. M. and Thompson, R. F. Habituation: A dual-process theory. Psychol. Rev., 1970, 77, No. 5, 419-450.

Guilford, J. P. Intelligence, Creativity, and Their Educational Implications. San Diego: Robert R. Knapp, 1968.

Guilford, J. P. The Nature of Human Intelligence. New York: McGraw-Hill Book Company, 1967.

Harlow, H. F. The formation of learning sets. Psychol. Rev., 1949, 56, 51-65.

Harlow, H. F. and Harlow, Margaret, K. Developmental aspects of emotional behavior. In Perry Black (Ed.), Physiological Correlates of Emotion, 1970. New York: Academic Press.

Hebb, D. O. The Organization of Behavior: A Neuropsychological Theory. New York: John Wiley & Sons, 1949.

Hilgard, E. R. and Bower, G. H. Theories of Learning, 1966, New York: Appleton, (3rd edition)

Holt, R. Imagery: The return of the ostracized. American Psychologist, 1964, 19, 254-64.

James, W. Principles of Psychology. New York: Holt, 1890, Vol. 1.

Kagan, J. The determinants of attention in the infant. American Scientist, 1970, 58, 298-306.

Keele, S. W. Movement control in skilled motor performance. Psychol. Bull., 1968, 70, 387-403.

Kleinmuntz, B. (Ed.), Problem Solving: Research, Method and Theory. New York: John Wiley and Sons, Inc., 1966.

Leuba, C. Images as conditioned sensations. J. exp. Psychol., 1940, 26, 345-351.

Levine, S. Stimulation in infancy. In reading from Scientific American, Psychobiology: The Biological Bases of Behavior, May 1960, 93-99.

Lewis, D. J. Sources of experimental amnesia. Psychol. Rev., 1969, 76, No. 5, 461-472.

Lotze, R. H. Medicinische Psychologie. Leipzig: Weidmann, 1852.

Luria, A. R. The Role of Speech in the Regulation of Normal and Abnormal Behavior. New York: Liveright, 1961.

Magoun, H. W. Advances in brain research with implications for learning. In K. H. Pribram (Ed.), On the Biology of Learning. New York: Harcourt Brace and World, Inc., 1969.

Mandler, G. From association to structure. Psychol. Rev., 1962, 69, No. 5, 415-427.

Mandler, G. Association and organization: Facts, fancies, and theories. In T. R. Dixon and D. L. Horton (Ed.), Verbal Behavior and General Behavior Theory, 1968, 109-119.

Max, L. W. Experimental study of the motor theory of consciousness: IV. Action current responses in the deaf during awakening, kinesthetic imagery and abstract thinking. J. of Comparative Psychology, 1937, 24, 301-344.

Max, L. W. An experimental study of the motor theory of consciousness: III. Action current responses in deaf mutes during sleep, sensory stimulation and dreams. J. of Comparative Psychology, 1935, 19, 469-486.

McGaugh, J. L. Time-dependent process in memory storage. Science, 1966, 1351-1358.

McGeoch, J. A. The Psychology of Human Learning, 1942, New York: Longmans.

McGuigan, F. J. Covert oral behavior during the silent performance of language tasks. Psychol. Bull., 1970, 74, No. 5, 309-326.

Melton, A. W. (Ed.), Categories of Human Learning. New York: Academic, 1964.

Michael, D. N. and Maccoby, N. Factors influencing the effects of student participation on verbal learning from films: Motivating versus practice effects, "feedback," and overt versus covert responding. In A. A. Lumsdaine (Ed.), Student Response in Programmed Instruction. Washington, D.C.: National Academy of Sciences -- National Research Council, 1961, 271-293.

Miller, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychol. Rev., 1956, 63, 81-97.

Miller, G. A., Galanter, E. and Pribram, K. H., Plans and The Structure of Behavior. New York: Henry Holt and Company, 1960.

Montague, W. E., Adams, J. A., and Kiess, H. O. Forgetting and natural language mediation. J. exp. Psychol., 1966, 72(6), 829-833.

Montague, W. E. and Kiess, H. O. The associability of CVC pairs. J. exp. Psychol. Monogr., 1968, 78(2), Part 2, 1-23.

Montague, W. E. and Wearing, A. J. The complexity of natural language mediators and its relation to paired-associate learning. Psychon. Sci., 1967a, 7, 135-136.

Montague, W. E. and Wearing, A. J. Natural language mediation: A source of interference with extra-experimental interference. Psychon. Sci., 1967b, 9, 317-318.

Mowrer, O. H. Two-factor learning theory reconsidered with special reference to secondary reinforcement and the concept of habit. Psychol. Rev., 1956, 63, 114-128.

Neimark, E. D. and Estes, W. K. Stimulus Sampling Theory. San Francisco: Holden-Day, 1967.

Neisser, U. Cognitive Psychology, 1967. New York: Meredith Publishing Co.

Norman, D. A. Toward a theory of memory and attention. Psychol. Rev., 1968, 75, No. 6, 522-536.

Norman, D. A. Memory and Attention. New York: John Wiley and Sons, Inc. 1969.

O'Connell, D. C. Facilitation of recall by linguistic structure in nonsense strings. Psychol. Bull., 1970, 74(6), 441-452.

Osgood, C. E. On understanding and creating sentences. Amer. Psychologist, 1963, 735-751.

Osgood, C. E. Toward a wedding of insufficiencies. In D. L. Horton and T. R. Dixon (Ed.), Verbal Behavior and General Behavior Theory, 1968, Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Paivio, A. On the functional significance of imagery. Psychol. Bull., 1970, 73(6), 385-392.

Paivio, A. Mental imagery in associative learning and memory. Psychol. Rev., 1969, 76, No. 3, 241-263.

Paivio, A. and Csapo, K. Concrete-image and verbal memory codes. J. exp. Psychol., 1969, 80, 279-285.

Paivio, A., Yuille, J. C., and Rogers, T. B. Noun imagery and meaningfulness in free and serial recall. J. exp. Psychol., 1969, 79, 509-514.

Paivio, A., Yuille, J. C., and Smythe, P. C. Stimulus and response abstractness, imagery, and meaningfulness, and reported mediators in paired-associate learning. Canadian Journal of Psychology, 1966, 20, 362-377.

Palermo, D. S. Imagery in children's learning: Discussion. Psychol. Bull., 1970, 73(6), 415-421.

Penfield, W. Consciousness, memory, and man's conditioned reflexes. In K. H. Pribram (Ed.), On the Biology of Learning. New York: Harcourt Brace and World, Inc., 1969.

Postman, L. Experimental analysis of learning to learn. In G. H. Bower and Janet T. Spence (Ed.), The Psychology of Learning and Motivation, 1969, 3, 241-296. New York: Academic Press.

Pribram, K. H. (Ed.) The four R's of remembering. On the Biology of Learning. New York: Harcourt, Brace and World, Inc., 1969.

Reese, H. W. Imagery and contextual meaning. Psychol. Bull., 1970, 73(6), 404-414.

Restle, F. Theory of serial pattern learning: Structural trees. Psychol. Rev., 1970, 77(6), 481-495.

Restle, F. and Brown, E. R. Serial pattern learning. J. exp. Psychol., 1970, 83, 120-125.

Rigney, J. W. and Towne, D. M. Computer techniques for analyzing the micro-structure of serial-action work in industry. Human Factors, 1969, 11(2), 113-122.

Rohwer, W. D., Jr. Images and pictures in children's learning: Research results and educational implications. Psychol. Bull., 1970, 73(6), 393-403.

Scandura, J. M. Role of rules in behavior: Toward an operational definition of what (rule) is learned. Psychol Rev., 1970, 77(6), 516-533.

Shepard, R. N. Comments on Professor Underwood's paper. In C. N. Cofer and Barbara S. Musgrave (Ed.), Verbal Behavior and Learning: Problems and Processes, 1963, 48-70.

Shepard, R. N. and Chipman, Susan. Second-order ismorphism of internal representations: Shapes of states. Cognitive Psychology, 1970, 1(1), 1-17.

Simon, H. The Sciences of the Artificial. Cambridge, Mass.: MIT Press, 1969.

Spence, K. W. and Spence, Janet T. (Ed.), The Psychology of Learning and Motivation. New York: Academic Press, 1968, 2.

Sternberg, S. Memory-scanning: Mental processes revealed by reaction-time experiments. American Scientist, 1969, 57(4), 421-457.

Suppes, P. and Morningstar, Mona. Computer-assisted instruction. Science, 1969, 166, 343-350.

Tapp, J. T. Reinforcement and Behavior. New York: Academic Press, 1969.

Taub, E. and Berman, A. J. Movement and learning in the absence of sensory feedback. In S. J. Freedman (Ed.), The Neuropsychology of Spatially Oriented Behavior. Homewood, Ill.: Dorsey Press, 1968.

Treisman, Anne M. Strategies and models of selective attention. Psychol. Rev., 1969, 76(3), 282-299.

Treisman, Anne M. Verbal cues, language and meaning in selective attention. Amer. J. Psychol., 1964, 77, 206-219.

Underwood, B. J. Attributes of memory. Psychol. Rev., 1969, 76(6), 559-573.

Warden, C. J., Fjeld, H. A. and Koch, A. M. Imitative behavior in Cebus and Rhesus monkeys. Pedagogical Seminary and Journal of Genetic Psychology, 1940, 56, 311-322.

Warden, C. J. and Jackson, T. A. Imitative behavior in the Rhesus monkey. Pedagogical Seminary and Journal of Genetic Psychology, 1935, 46, 103-125.

Washburn, S. L. and Devore, I. The social life of baboons. Psychobiology: The Biological Bases of Behavior. San Francisco: W. H. Freeman, 1961, 10-19.

Zeaman, D. and House, Betty, J. The relation of IQ and learning. In R. M. Gagne (Ed.), Learning and Individual Differences. Columbia, Ohio: Merrill Books, 1967, 192-212.

OFFICE OF NAVAL RESEARCH

PERSONNEL AND TRAINING RESEARCH PROGRAMS (Code 458)

DISTRIBUTION LIST

Contract No. N00014-67-A-0269-0012
Contractor: Dr. Joseph W. Rigney

Navy

4 Chief of Naval Research
Code 458
Department of the Navy
Washington, D. C. 20360

1 Director
ONR Branch Office
495 Summer Street
Boston, Massachusetts 02210

1 Office of Naval Research
Branch Office Chicago
536 South Clark Street
Chicago, Illinois 60605

1 Director
ONR Branch Office
1030 East Green Street
Pasadena, California 91101

6 Director, Naval Research Laboratory
Washington, D. C. 20390
ATTN: Library, Code 2029 (ONRL)

1 Office of Naval Research
Area Office
207 West 24th Street
New York, New York 10011

1 Office of Naval Research
Area Office
1076 Mission Street
San Francisco, California 94103

6 Director
Naval Research Laboratory
Washington, D. C. 20390
ATTN: Technical Information Div.

12 Defense Documentation Center
Cameron Station, Building 5
5010 Duke Street
Alexandria, Virginia 22314

1 Commanding Officer
Service School Command
U.S. Naval Training Center
San Diego, California 92133

3 Commanding Officer
Naval Personnel and Training
Research Laboratory
San Diego, California 92152

1 Commanding Officer
Naval Medical Neuropsychiatric
Research Unit
San Diego, California 92152

1 Commanding Officer
Naval Air Technical Training Center
Jacksonville, Florida 32213

1 Dr. James J. Regan, Code 55
Naval Training Device Center
Orlando, Florida 32813

1 Dr. Mortin A. Bertin
Educational Testing Service
20 Nassau Street
Princeton, New Jersey 08540

1 Mr. Marvin Denicoff
Director, Information Systems Programs
Office of Naval Research (Code 437)
Arlington, Virginia 22217

1 Technical Library
U. S. Naval Weapons Laboratory
Dahlgren, Virginia 22448

1 Research Director, Code 06
Research and Evaluation Department
U. S. Naval Examining Center
Building 2711 - Green Bay Area
Great Lakes, Illinois 60088
ATTN: C.S. Winiewicz

1 Chairman
Behavioral Science Department
Naval Command and Management Division
U. S. Naval Academy
Luce Hall
Annapolis, Maryland 21402

1 Dr. A. L. Slafkosky
Scientific Advisor (Code AX)
Commandant of the Marine Corps
Washington, D. C. 20380

1 Behavioral Sciences Department
Naval Medical Research Institute
National Naval Medical Center
Bethesda, Maryland 20014

1 Commanding Officer
Naval Medical Field Research Laboratory
Camp Lejeune, North Carolina 28542

1 Director
Aerospace Crew Equipment Department
Naval Air Development Center
Johnsville
Warminster, Pennsylvania 18974

1 Chief
Naval Air Technical Training
Naval Air Station
Memphis, Tennessee 38115

1 Director
Education and Training Sciences Dept.
Naval Medical Research Institute
National Naval Medical Center
Building 142
Bethesda, Maryland 20014

1 Commander
Submarine Development Group Two
Fleet Post Office
New York, New York 09501

1 Mr. Joseph B. Blankenheim
NAVELEX 0474
Munitions Building, Room 3721
Washington, D. C. 20360

1 Commander
Operational Test & Evaluation Force
U. S. Naval Base
Norfolk, Virginia 23511

1 Mr. S. Friedman
Special Assistant for Research & Studies
OASN (M&RA)
The Pentagon, Room 4E794
Washington, D. C. 20350

1 Chief of Naval Operations, (Op-07TL)
Department of the Navy
Washington, D. C. 20350

1 Deputy Director
Office of Civilian Manpower Management
Department of the Navy
Washington, D. C. 20390

1 Chief of Naval Material (MAT 031M)
Room 1323, Main Navy Building
Washington, D. C. 20360

1 Mr. George N. Graine
Naval Ship Systems Command (SHIP 03H)
Department of the Navy
Washington, D. C. 20360

1 Chief
Bureau of Medicine and Surgery
Code 513
Washington, D. C. 20390

1 Chief
Bureau of Medicine and Surgery
Research Division (Code 713)
Department of the Navy
Washington, D. C. 20390

6 Technical Library (Pers-11b)
Bureau of Naval Personnel
Department of the Navy
Washington, D. C. 20370

3 Personnel Research and Development Laboratory
Washington Navy Yard, Building 200
Washington, D. C. 20390
ATTN: Library, Room 3307

1 Commander, Naval Air Systems Command
Navy Department, AIR-4132
Washington, D. C. 20360

1 Commandant of the Marine Corps
Headquarters, U. S. Marine Corps
Code A01B
Washington, D. C. 20380

1 Technical Library Branch
Naval Ordnance Station
Indian Head, Maryland 93940

1 Library, Code 0212
Naval Postgraduate School
Monterey, California 93940

1 Technical Reference Library
Naval Medical Research Institute
National Naval Medical Center
Bethesda, Maryland 20014

1 Technical Library
Naval Ordnance Station
Louisville, Kentucky 40214

1 Naval Undersea Research and Development Center
3202 East Foothill Boulevard
Pasadena, California 91107
ATTN: Code 161

1 Commanding Officer
U. S. Naval Schools Command
Mare Island
Vallejo, California 94592

1 Scientific Advisory Team (Code 71)
Staff, COMASWFORLANT
Norfolk, Virginia 23511

3 Technical Director
Personnel Research Division
Bureau of Naval Personnel
Washington, D. C. 20370

1 Deputy
Office of Civilian Manpower Management
Department of the Navy
Washington, D. C. 20390

1 Technical Library
Naval Ship Systems Command
Main Navy Building, Room 1532
Washington, D. C. 20360

1 Technical Library
Naval Training Device Center
Orlando, Floridia 32813

1 Chief, Naval Air Reserve Training
Naval Air Station
Box 1
Glenview, Illinois 60026

1 Dr. Earl I. Jones
Director
Naval Training Research Institute
Naval Personnel & Training
Research Laboratory
San Diego, California

1 Head, Personnel Measurement Staff
Capital Area Personnel Service Office-
Navy
Ballston Tower #2, Room 1204
801 N. Randolph Street
Arlington, Virginia 22203

<u>Army</u>

1 Director of Research
U. S. Army Armor Human Research Unit
Fort Knox, Kentucky 40121
ATTN: ATSAG-EA

1 Armed Forces Staff College
Norfolk, Virginia 23511
ATTN: Library

1 Director
Behavioral Sciences Laboratory
U. S. Army Research Institute of
Environmental Medicine
Natick, Massachusetts 01760

1 Chief, Training and Development Div.
Office, Deputy Chief of Staff for
Personnel
Department of the Army
Washington, D. C. 20310

1 U. S. Army Behavior and Systems
Research Laboratory
Commonwealth Building, Room 239
1320 Wilson Boulevard
Arlington, Virginia 22209

1 Division of Neuropsychiatry
Walter Reed Army Institute of
Research
Walter Reed Army Medical Center
Washington, D. C. 20012

1 Behavioral Sciences Division
Office of Chief of Research and
Development
Department of the Army
Washington, D. C. 20310

1 Dr. Vincent Cieri
Training Advisor
USA Signal School
Ft. Monmouth, New Jersey 07703

1 Commandant
U. S. Army Adjutant General School
Fort Benjamin Harrison, Indiana 46216
ATTN: ATSAG-EA

1 Dr. George S. Harker, Director
Experimental Psychology Division
U. S. Army Medical Research Lab.
Fort Knox, Kentucky 40121

1 LTC William C. Cosgrove
USA CDC Personnel & Administrative
Services Agency
Ft. Benjamin Harrison, Indiana 46216

Air Force

1 Director
Air University Library
Maxwell Air Force Base, Alabama 36112
ATTN: AUL-8110

1 Headquarters, Electronic Systems Div.
ATTN: Dr. Sylvia Mayer/ESMDA
L. G. Hanscom Field
Bedford, Massachusetts 01730

1 Commandant
U. S. Air Force School of Aerospace Medicine
ATTN: Aeromedical Library (SMSL-4)
Brooks Air Force Base, Texas 78235

1 AFHRL (TR/Dr. G. A. Eckstrand)
Wright-Patterson Air Force Base
Ohio 45433

1 Personnel Research Division (AFHRL)
Lackland Air Force Base
San Antonio, Texas 78236

1 AFOSR(SRLB)
1400 Wilson Boulevard
Arlington, Virginia 22209

1 Headquarters, U. S. Air Force
Chief, Personnel Research and Analysis Division (AFPDPL)
Washington, D. C. 20330

1 Headquarters, U. S. Air Force
AFPTRBD
Programs Resources and Technology Div.
Washington, D. C. 20330

1 AFHRL (HRTT/Dr. Ross L. Morgan)
Wright-Patterson Air Force Base
Ohio 45433

1 Lt. Col. John E. Dulfer
HQ, AFSC (SDEC)
Andrews Air Force Base
Washington, D. C. 20330

DOD

1 LTCOL F. R. Ratliff
Office of the Assistant Secretary of Defense (M&RU)
The Pentagon, Room 3D960
Washington, D. C. 20301

1 Dr. Ralph R. Canter
Military Manpower Research Coordinator
OASD (M&RA) MR&U
The Pentagon, Room 3D960
Washington, D. C. 20301

Government

1 Dr. Thomas E. Moorefield, Chief
Basic Studies Branch, DESER
U. S. Office of Education
Dept. of Health, Education & Welfare
Washington, D. C. 20202

1 Mr. A. Mayrhofer
Office of Associate Commissioner
Bureau of Elementary & Secondary Education
U. S. Office of Education
Dept. of Health, Education & Welfare
Washington, D. C. 20202

1 Dr. Andrew R. Molnar
Computer Innovation in Education Section
Office of Computing Activities
National Science Foundation
Washington, D. C. 20550

1 Dr. Alvin E. Goins, Executive Secretary
Personality and Cognition Research Review Committee
Behavioral Sciences Research Branch
National Institute of Mental Health
5454 Wisconsin Avenue, Room 10A02
Chevy Chase, Maryland 20015

1 Office of Computer Information
Center for Computer Sciences and
Technology
National Bureau of Standards
Washington, D. C. 20234

2 Executive Secretariat
Interagency Committee on Manpower
Research, Room 251-A
1111 Twentieth Street, N.W.
Washington, D. C. 20036

1 Director, National Center for
Educational Research & Development
U. S. Office of Education
Dept. of Health, Education & Welfare
Washington, D. C. 20202

1 Mr. Joseph J. Cowan, Chief
Psychological Research Branch (P-1)
U. S. Coast Guard Headquarters
400 Seventh Street, S. W.
Washington, D. C. 20226

Non-Government

1 ERIC Clearinghouse on Vocational
and Technical Education
The Ohio State University
1900 Kenny Road
Columbus, Ohio 43210
ATTN: Acquisition Specialist

1 ERIC Clearinghouse on
Educational Media and Technology
Stanford University
Palo Alto, California 94305

1 Dr. Don H. Coombs, Co-Director
ERIC Clearinghouse
Stanford University
Palo Alto, California 94305

1 Dr. Richard C. Atkinson
Department of Psychology
Stanford University
Palo Alto, California 94305

1 Dr. Jaime R. Carbonell
Bolt, Beranek & Newman, Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

1 Dr. Richard S. Hatch
Decision Systems Associates, Inc.
11428 Rockville Pike
Rockville, Maryland 20852

1 Director
Human Resources Research Organization
300 North Washington Street
Alexandria, Virginia 22314

1 Human Resources Research Organization
Division #1, Systems Operations
300 North Washington Street
Alexandria, Virginia 22314

1 Human Resources Research Organization
Division #3, Recruit Training
Post Office Box 5787
Presidio of Monterey, California 93940

1 Human Resources Research Organization
Division #5, Air Defense
Post Office Box 6021
Fort Bliss, Texas 79916

1 Human Resources Research Organization
Division #4, Infantry
Post Office Box 2086
Fort Benning, Georgia 31905

1 Human Resources Research Organization
Division #6, Aviation
Post Office Box 428
Fort Rucker, Alabama 36360

1 Dr. Edward R. F. W. Crossman
Department of Industrial Engineering
University of California
Berkeley, California 94720

ERIC

1 Dr. F. J. Divesta
Pennsylvania State University
320 Rackley Building
University Park, Pennsylvania 16802

1 Dr. Robert Dubin
Graduate School of Administration
University of California
Irvine, California 02650

1 Dr. Robert J. Seidel
Human Resources Research Organization
300 N. Washington Street
Alexandria, Virginia 22314

1 Dr. Marvin D. Dunnette
University of Minnesota
Department of Psychology
Elliot Hall
Minneapolis, Minnesota 55455

1 Mr. Wallace Feurzeig
Bolt, Beranek and Newman, Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

1 S. Fisher, Research Associate
Computer Facility
Graduate Center
City University of New York
33 West 42nd Street
New York, New York 10036

1 Dr. John C. Flanagan
American Institutes for Research
Post Office Box 1113
Palo Alto, California 94302

1 Dr. Robert Glaser
Learning Research and Development Center
University of Pittsburgh
Pittsburgh, Pennsylvania 15213

1 Dr. Albert S. Glickman
American Institutes for Research
8555 Sixteenth Street
Silver Spring, Maryland 20910

1 Dr. Bert Green
Department of Psychology
Johns Hopkins University
Baltimore, Maryland 21218

1 Dr. Duncan N. Hansen
Center for Computer Assisted Instruction
Florida State University
Tallahassee, Florida 32306

1 Dr. M. D. Havron
Human Sciences Research, Inc.
Westgate Industrial Park
7710 Old Springhouse Road
McLean, Virginia 22101

1 Dr. Carl E. Helm
Department of Educational Psychology
Graduate Center
City University of New York
33 West 42nd Street
New York, New York 10036

1 Dr. Albert E. Hickey
Entelek, Incorporated
42 Pleasant Street
Newburyport, Massachusetts 01950

1 Mr. Harry H. Harman
Division of Computation Sciences
Educational Testing Service
Princeton, New Jersey 08540

1 Dr. C. Victor Bunderson
Computer Assisted Instruction Laboratory
University of Texas
Austin, Texas 78712

1 Dr. Lee J. Cronbach
School of Education
Stanford University
Palo Alto, California 94305

1 Psychological Abstracts
American Psychological Association
1200 Seventeenth Street, N.W.
Washington, D. C. 20036

1 Dr. Bernard M. Bass
University of Rochester
Management Research Center
Rochester, New York 14627

1 Dr. Lee R. Beach
Department of Psychology
University of Washington
Seattle, Washington 98105

1 Mr. Edmund C. Berkeley
Computers and Automation
815 Washington Street
Newtonville, Massachusetts 02160

1 Dr. Roger A. Kaufman
Graduate School of Leadership
& Human Behavior
U. S. International University
8655 E. Pomerada Rd.
San Diego, California 92124

1 Dr. George E. Rowland
Rowland and Company, Inc.
Post Office Box 61
Haddonfield, New Jersey 08033

1 Dr. Mats Bjorkman
University of Umea
Department of Psychology
Umea 6, Sweden

1 Mr. Roy Ference
Room 2311
U. S. Civil Service Commission
Washington, D. C. 20415

1 Dr. Frederic M. Lord
Educational Testing Service
20 Nassau Street
Princeton, New Jersey 08540

1 Dr. Robert R. Mackie
Human Factors Research, Inc.
Santa Barbara Research Park
6780 Cortona Drive
Goleta, California 93017

1 Dr. Stanley M. Nealey
Department of Psychology
Colorado State University
Fort Collins, Colorado 80521

1 Dr. Gabriel D. Ofiesh
Center for Educational Technology
Catholic University
4001 Harewood Road, N.E.
Washington, D. C. 20017

1 Mr. Luigi Petrullo
2431 North Edgewood Street
Arlington, Virginia 22207

1 Dr. Len Rosenbaum
Psychology Department
Montgomery College
Rockville, Maryland 20852

1 Dr. Arthur I. Siegel
Applied Psychological Services
Science Center
404 East Lancaster Avenue
Wayne, Pennsylvania 19087

1 Dr. Paul Slovic
Oregon Research Institute
Post Office Box 3196
Eugene, Oregon 97403

1 Dr. Diane M. Ramsey-Klee
R-K Research & System Design
3947 Ridgemont Drive
Malibu, California 90265

1 Dr. Ledyard R. Tucker
University of Illinois
Psychology Building
Urbana, Illinois 61820

1 Dr. Benton J. Underwood
Department of Psychology
Northwestern University
Evanston, Illinois 60201

1 Dr. John Annett
Department of Psychology
Hull University
Hull
Yorkshire, England

1 Dr. Lloyd G. Humphreys
Assistant Director for Education
National Science Foundation
Washington, D. C. 20550

1 Educational Testing Service
Division of Psychological Studies
Rosedale Road
Princeton, New Jersey 08540

1 Dr. Harold Gulliksen
Department of Psychology
Princeton University
Princeton, New Jersey 08033